Gao et al. BMC Medicine (2024) 22:507
https://doi.org/10.1186/s12916-024-03721-4

BMC Medicine

RESEARCH

Open Access

Identification of sensitive periods of weight status transition over the lifespan in Chinese population

Chaonan Gao[1], Xin Meng[1], Wei Liu[1], Qianjin Qi[1] and Yinkun Yan[1*]

Abstract

Background The prevalence of high body mass index (BMI) is increasing in both children and adults worldwide. However, it is unclear whether vulnerabilities to maintenance and transition of weight status vary throughout the lifespan.

Objective We aimed to characterize dynamic transitions of weight statuses across different life stages and to identify the sensitive periods for maintenance, onset, and resolution of obesity.

Methods This longitudinal study included a total of 23,179 participants aged 6–80 years with 95,994 BMI measurements from the China Health and Nutrition Survey 1989–2015. To examine the heterogeneity in transitions of weight statuses across different life stages, we divided participants into 8 sub-cohorts based on baseline ages by 10-year intervals, i.e., 6–10 years, 11–20 years, 21–30 years, 31–40 years, 41–50 years, 51–60 years, 61–70 years, and 71–80 years. We estimated the probabilities of transitioning between weight statuses at a given follow-up year by baseline age using generalized linear mixed-effects models.

Results The predicted prevalence of obesity decreased from 6 years, bottomed at around 20 years, increased thereafter, peaked at around 55 years, and then decreased gradually. In general, participants with underweight had lower probabilities of maintaining the same status compared to those with normal weight, overweight, or obesity for all age groups. For 10-year follow-up, individuals aged 21–30 years had the highest probabilities of transitioning from normal weight to obesity and transitioning from overweight to obesity compared to those in other age groups. Individuals aged 6–20 years had the highest probabilities of transitioning from obesity to normal weight and transitioning from overweight to normal weight. Individuals in all adult age groups had higher probabilities of maintaining obesity status than children and adolescents.

Conclusions Young adulthood is the most sensitive period for obesity onset, whereas childhood and adolescence are the most sensitive periods for obesity resolution. The findings suggest the heterogeneity of susceptibilities to weight status transitions across different life stages and highlight the importance of the development of age-appropriate approaches for the prevention and intervention of obesity.

Keywords Overweight, Obesity, Transition, Lifespan, Sensitive periods

*Correspondence:
Yinkun Yan
ykyan2011@163.com
[1] Center for Non-Communicable Disease Management, Beijing Children's Hospital, Capital Medical University, National Center for Children's Health, Beijing, China

Background

The prevalence of obesity has been increasing and represents a major public health issue in China and worldwide [1]. Obesity in adults is associated with increased risks of multiple health consequences, including cardiovascular disease [2, 3], diabetes [4], and mortality [5]. Several lifespan studies have reported that excess weight in childhood, as well as weight changes and weight trajectories from childhood to adulthood, has been associated with risks of adult cardiometabolic diseases [6–9]. Current obesity prevention and intervention strategies are not age-targeted and thus are inadequate for addressing the obesity epidemic [10]. Individuals are susceptible to excess weight at all ages of lifespan, but the extent of weight fluctuation and weight status transition may vary across different life periods. Thus, the determination of sensitive periods of transitions across weight statuses is important to identify the high-risk age groups, which may aid in the development of age-appropriate approaches to the prevention and intervention of obesity and its related diseases.

Large-scale cross-sectional studies have shown that the prevalence of obesity increases from young to middle adulthood and decreases during aging [11–13]; yet, these studies cannot investigate the dynamic transition of body mass index (BMI) statuses within individuals due to the cross-sectional design. Longitudinal studies have demonstrated that BMI tracks from childhood to adulthood, and childhood obesity strongly predicts the risk of adult obesity [14–18]. However, whether the susceptibilities for maintenance and transition of weight statuses (especially for onset and resolution of obesity) differ across different life stages remains unclear.

In the present study, using longitudinal data from the China Health and Nutrition Survey (CHNS) cohort study, we aimed to examine the exact patterns of maintenance and transition across weight statuses at different life stages and to determine the sensitive periods of onset and resolution of obesity in a Chinese population.

Methods

Study population and design

Data were from the CHNS, an international collaborative project between the National Institute for Nutrition and Health of the Chinese Center for Disease Control and Prevention and the University of North Carolina in Chapel Hill. The survey procedures have been described in detail elsewhere [19, 20]. In brief, the CHNS is a dynamic cohort study based on multiple cross-sectional surveys conducted in 1989, 1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011, and 2015. To examine the maintenance and transition of weight statuses over time, we linked these cross-sectional examinations to obtain repeated BMI measurements within individuals, and 35,841 individuals were initially included. Then, we excluded individuals who had stroke or myocardial infarction or were taking antidiabetic drugs, individuals whose BMI was > 3 standard deviations above the mean or < 3 standard deviations below the mean stratified for sex and age, individuals whose baseline age was > 80 years or < 6 years, and individuals who had only one BMI measurement. Finally, we included a total of 23,179 participants with 95,994 BMI measurements for overall longitudinal analyses. Of the 23,179 participants, 15,579 were included for 10-year follow-up analyses and 8025 were included for 20-year follow-up analyses (Additional file 1: Fig. S1). The CHNS was approved by the institutional review boards of the University of North Carolina at Chapel Hill, the Ministry of Health of the People's Republic of China, the National Institute for Nutrition and Health, and the Chinese Center for Disease Control and Prevention. Informed consent was obtained from participants or their parents.

Measurements

Standardized protocols were used by trained examiners. Height and weight were measured in all surveys. Standing height was measured without shoes to the nearest 0.2 cm using a portable stadiometer (SECA, Hamburg, Germany). Weight in light clothing without shoes was measured to the nearest 0.1 kg on a dedicated scale that was routinely calibrated. BMI was calculated as weight in kilograms divided by height in meters squared. For children and adolescents, underweight, overweight, and obesity were defined according to BMI cut-offs for Chinese children and adolescents aged 6–18 years [21, 22]. For adults, underweight was defined as BMI < 18.5 kg/m^2, normal weight was defined as 18.5 kg/m^2 ≤ BMI < 24.0 kg/m^2, overweight was defined as 24.0 kg/m^2 ≤ BMI < 28.0 kg/m^2, and obesity was defined as BMI ≥ 28.0 kg/m^2 [23].

Statistical methods

To compare weight status transitions across different life periods, we grouped participants into 8 sub-cohorts by their baseline ages, i.e., 6–10 years, 11–20 years, 21–30 years, 31–40 years, 41–50 years, 51–60 years, 61–70 years, and 71–80 years. To calculate the probabilities of maintenance and transition of weight status at 10-year follow-up and 20-year follow-up, we selected the BMI measurements for analyses which were closest with 10-year and 20-year follow-up time points from individuals who had measurements taken during time windows of 6 to 15 years and 16 to 25 years, respectively. We used a generalized linear mixed-effects model to estimate age-specific BMI levels and proportions of weight statuses during 6–80 years. We calculated age-adjusted correlation coefficients to describe the BMI tracking correlations at 10-year follow-up and 20-year follow-up. We also used a generalized linear mixed-effects model to estimate the maintenance and transition probabilities of weight statuses at any given follow-up year stratified by baseline age. The mixed model incorporated fixed and random effects, which allowed the intercept, linear, and nonlinear parameters to vary from individual to individual [24]. This model allowed for repeated measurements and different numbers of unequally spaced observations across individuals. Akaike information criterion (AIC) was used for model selection [25]. The model construction was on the basis of AIC and *P* values of the polynomial terms of the independent variable (follow-up years or age) at the significance level of 0.05. Follow-up years or age and their polynomial terms were included one by one for the model-building. The higher-order terms of follow-up years or age were not included in the model if they were not significant, or made lower-order terms not significant, or did not improve the goodness of fit of the model on the basis of AIC values. For instance, when we estimated the transition probabilities from normal weight to obesity over follow-up time, follow-up year was set as independent variable, and the polynomial terms of follow-up year were set as fixed effect and random effect simultaneously. Follow-up weight status (1, obesity; 0, non-obesity) was set as dependent variable. All statistical analyses were performed using the R software (version 4.2.3).

Results

Characteristics of study participants

The characteristics of study participants for all age groups are shown in Table 1. For overall longitudinal analyses, we included 23,179 participants. The sample size ranged from 1594 in the 71–80 year age group to 6988 in the 31–40 year age group, and the medians (interquartile ranges) of follow-up length ranged from 6 years (6–13 years) in 11–20 year age group to 11 years (4–19 years) in 21–30 year age group. For 10-year follow-up analyses of weight status transition, we included 15,579 participants with the sample size ranging from 978 in the 71–80 year age group to 5450 in the 31–40 year age group (Additional file 1: Table S1). For 20-year follow-up analyses, we included 8025 participants with the sample size ranging from 58 in the 71–80 year age group to 3026 in the 31–40 year group (Additional file 1: Table S2).

Age-related changes in BMI levels and statuses over the lifespan

The BMI levels and proportions of weight statuses changed with age over the lifespan overall and for both sexes (Fig. 1). For overall analyses, BMI levels increased from 6 years, peaked at around 40 to 55 years, and decreased gradually thereafter. The prevalence of obesity decreased from 6 years, bottomed at around 20 years, increased dramatically thereafter, peaked at around 55 years, and then decreased slightly. The prevalence of overweight showed similar age-related change patterns, whereas the proportions of normal weight and underweight showed opposite age-related change patterns (Fig. 1). For sex-stratified analyses, males versus females had similar lifespan change patterns, but males had earlier peak ages for BMI levels and obesity prevalence, with obesity peaking at around 55–60 years in males and around 60–65 years in females.

Tracking correlations of BMI levels by age and weight status

In general, the BMI tracking correlations decreased with follow-up length for all age and weight status groups (Fig. 2). Participants aged 6–20 years had smaller BMI tracking correlation coefficients compared with participants in other age groups for both 10-year follow-up and 20-year follow-up. Participants with underweight had lower BMI tracking correlations compared with participants with normal weight, overweight, or obesity. In addition, males versus females had no significant difference in BMI tracking correlations for most subgroups of age and weight status (Additional file 1: Fig. S2-S3).

Maintenance of weight statuses across different age periods

Figure 3 shows the probabilities of maintaining the same weight status and transitioning from one to another weight status by age group at 10-year follow-up. For instance, for participants with normal weight aged 6–10 years, 13.7% transitioned to underweight, 80.3% maintained normal weight, 5.2% transitioned to overweight, and 0.8% transitioned to obesity after 10-year follow-up. In general, the maintenance probabilities of weight statuses decreased with follow-up length overall and for sex and age subgroups (Fig. 3, Additional file 1: Fig. S4). Compared with participants with overweight or obesity, participants with underweight had lower maintenance probabilities at 10-year follow-up for most age groups, whereas participants with normal weight had higher maintenance probabilities. For participants with normal weight, those aged 21–40 years had lower maintenance probabilities compared to those in other age groups at 10-year follow-up. For participants with overweight or obesity, those aged 6–20 years had lower maintenance probabilities compared to those in other age groups. For participants with underweight, those aged 6–40 years had the lowest maintenance probabilities.

Table 1 Characteristics of study participants

	6–10 years	11–20 years	21–30 years	31–40 years	41–50 years	51–60 years	61–70 years	71–80 years
Total								
N	3947	4997	5600	6988	6788	5756	3581	1594
Baseline age, years[a]	7.57 (1.35)	14.15 (2.98)	24.93 (2.84)	34.38 (2.79)	43.58 (2.62)	53.74 (2.65)	63.37 (2.42)	73.04 (2.24)
Baseline BMI, kg/m^2[a]	15.58 (2.09)	18.43 (2.76)	21.52 (2.68)	22.45 (2.88)	23.13 (3.07)	23.28 (3.29)	22.94 (3.43)	22.34 (3.47)
Baseline weight status, *n* (%)								
Underweight	499 (12.6)	715 (14.3)	490 (8.8)	371 (5.3)	233 (3.4)	294 (5.1)	305 (8.5)	185 (11.6)
Normal weight	2845 (72.1)	3900 (78.0)	4212 (75.2)	4745 (67.9)	4135 (60.9)	3224 (56.0)	1965 (54.9)	944 (59.2)
Overweight	331 (8.4)	311 (6.2)	763 (13.6)	1564 (22.4)	1937 (28.5)	1704 (29.6)	1010 (28.2)	366 (23.0)
Obesity	272 (6.9)	71 (1.4)	135 (2.4)	308 (4.4)	483 (7.1)	534 (9.3)	301 (8.4)	99 (6.2)
Follow-up length, year[b]	7 (4, 12)	6 (3, 13)	11 (4, 19)	11 (6, 19)	11 (5, 17)	8 (4, 14)	6 (4, 11)	6 (4, 9)
Males								
N	2095	2723	2730	3324	3251	2749	1710	711
Baseline age, years[a]	7.55 (1.33)	14.14 (2.96)	24.60 (2.85)	34.48 (2.81)	43.69 (2.67)	53.75 (2.61)	63.32 (2.35)	72.98 (2.15)
Baseline BMI, kg/m^2[a]	15.77 (2.11)	18.40 (2.73)	21.55 (2.68)	22.53 (2.88)	22.97 (3.03)	22.94 (3.10)	22.70 (3.30)	22.24 (3.35)
Baseline weight status, n(%)								
Underweight	269 (12.8)	468 (17.2)	205 (7.5)	166 (5.0)	118 (3.6)	133 (4.8)	148 (8.7)	86 (12.1)
Normal weight	1488 (71.0)	2025 (74.4)	2102 (77.0)	2223 (66.9)	2050 (63.1)	1687 (61.4)	988 (57.8)	427 (60.1)
Overweight	180 (8.6)	187 (6.9)	348 (12.7)	778 (23.4)	858 (26.4)	730 (26.6)	466 (27.3)	162 (22.8)
Obesity	158 (7.5)	43 (1.6)	75 (2.7)	157 (4.7)	225 (6.9)	199 (7.2)	108 (6.3)	36 (5.1)
Follow-up length, year[b]	7 (4, 15)	9 (4, 15)	11 (5, 20)	11 (6, 18)	11 (5, 17)	7 (4, 13)	6 (4, 11)	6 (4, 9)
Females								
N	1852	2274	2870	3664	3537	3007	1871	883
Baseline age, years[a]	7.60 (1.36)	14.15 (3.01)	25.25 (2.80)	34.30 (2.78)	43.48 (2.57)	53.73 (2.69)	63.42 (2.48)	73.08 (2.32)
Baseline BMI, kg/m^2[a]	15.38 (2.05)	18.48 (2.80)	21.50 (2.68)	22.37 (2.88)	23.28 (3.09)	23.59 (3.42)	23.16 (3.53)	22.42 (3.57)
Baseline weight status, n(%)								
Underweight	230 (12.4)	247 (10.9)	285 (9.9)	205 (5.6)	115 (3.3)	161 (5.4)	157 (8.4)	99 (11.2)
Normal weight	1357 (73.3)	1875 (82.5)	2110 (73.5)	2522 (68.8)	2085 (58.9)	1537 (51.1)	977 (52.2)	517 (58.6)
Overweight	151 (8.2)	124 (5.5)	415 (14.5)	786 (21.5)	1079 (30.5)	974 (32.4)	544 (29.1)	204 (23.1)
Obesity	114 (6.2)	28 (1.2)	60 (2.1)	151 (4.1)	258 (7.3)	335 (11.1)	193 (10.3)	63 (7.1)
Follow-up length, year[b]	7 (4, 9)	5 (2, 9)	11 (4, 18)	11 (6, 20)	11 (5, 18)	9 (4, 15)	7 (4, 11)	6 (4, 9)

[a] Data were described as mean (standard deviation)

[b] Data were described as median (interquartile range)

Transition of weight statuses across different age periods

As shown in Fig. 3, for participants with normal weight, those aged 31–40 years had the highest probabilities of transitioning to overweight at 10-year follow-up, those aged 21–30 years had the highest probabilities of transitioning to obesity, and those aged 6–10 years or 71–80 years had the highest probabilities of transitioning to underweight among all age groups. For participants with overweight, those aged 21–30 years had the highest probabilities of transitioning to obesity, whereas those aged 6–20 years had the highest probabilities of transitioning to normal weight among all age groups. For participants with obesity, those aged 6–20 years had the highest probabilities of transitioning to normal weight among all age groups. For participants with underweight, a large proportion transitioned to normal weight for all age groups with the probabilities ranging from 31.1% in the 71–80 year age group to 69.2% in the 31–40 year age group.

Additional analyses

We performed additional analyses for maintenance and transition of weight status at 20-year follow-up and found similar results (Additional file 1: Fig. S4). We also performed additional analyses stratified by sex, and males versus females showed similar results (Additional file 1: Fig. S5-S8). Furthermore, we mapped the change in maintenance and transition probabilities of weight status at a given follow-up year ranging from 0 to 20 years (Fig. 4, Additional file 1: Fig. S9-S10).

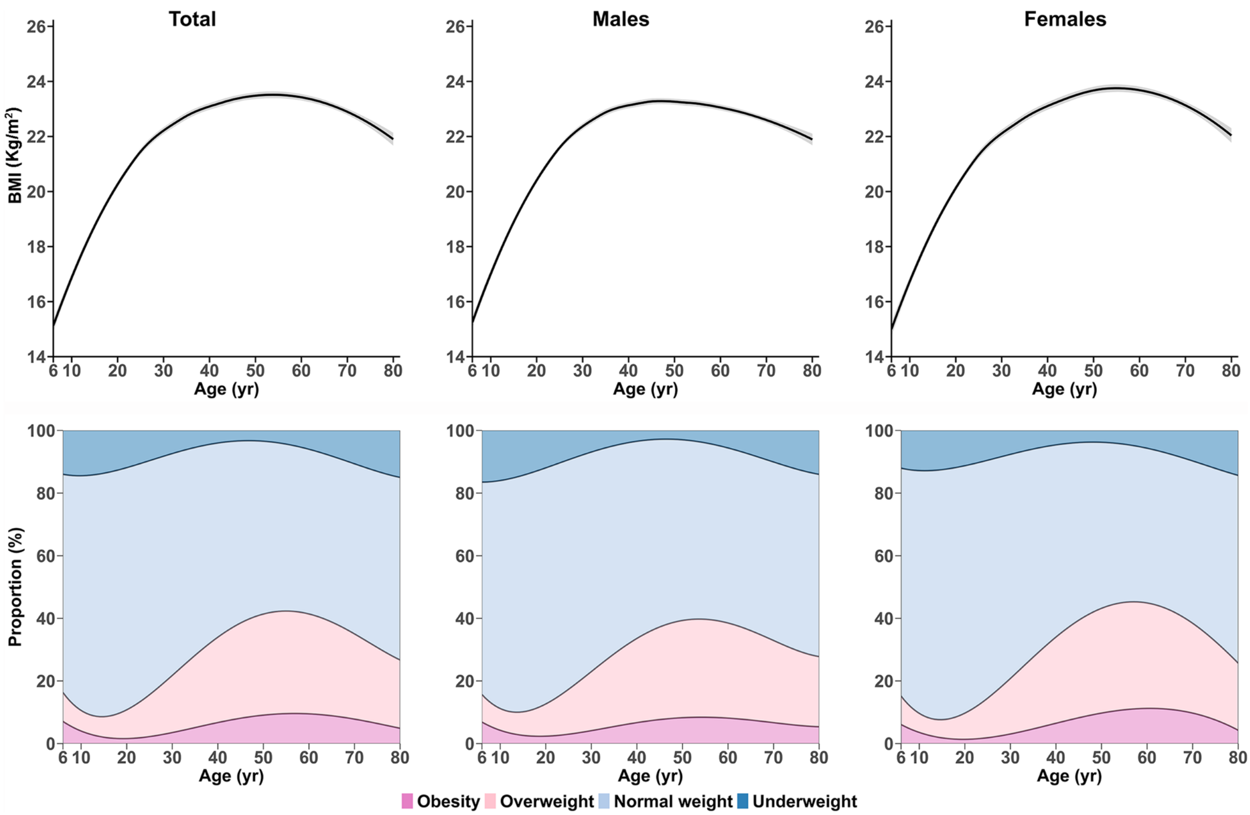

Fig. 1 Age-related change in BMI levels and proportions of weight statuses

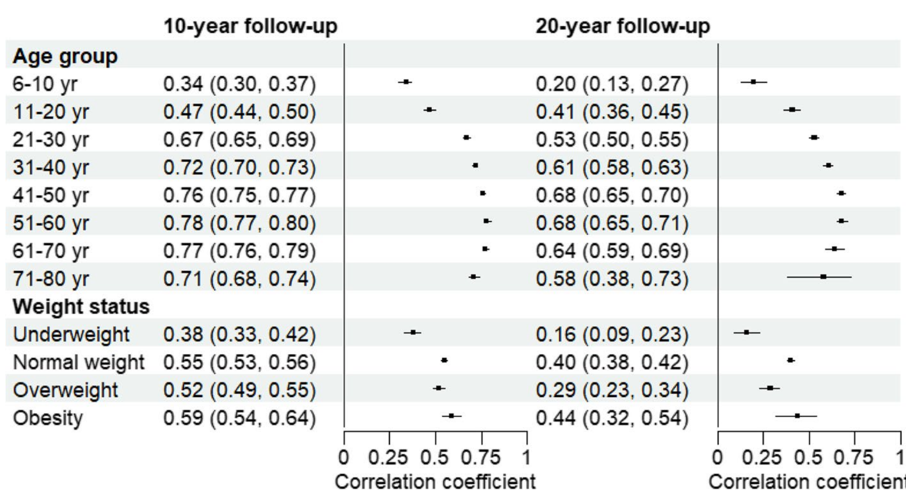

Fig. 2 Tracking correlation coefficients of BMI by baseline age and weight status

Discussion

In this large-scale cohort study with ages ranging from 6 to 80 years, we characterized age-related changes in proportions of weight statuses and examined dynamic transitions of weight statuses over time across different life stages to identify sensitive periods for maintenance, onset, and resolution of obesity. Our principal findings are fourfold. First, the prevalence of obesity varied with age and peaked in middle and older adulthood. Second, young adulthood is the most sensitive period for obesity onset. Third, childhood and adolescence are the most sensitive periods for obesity resolution. Finally,

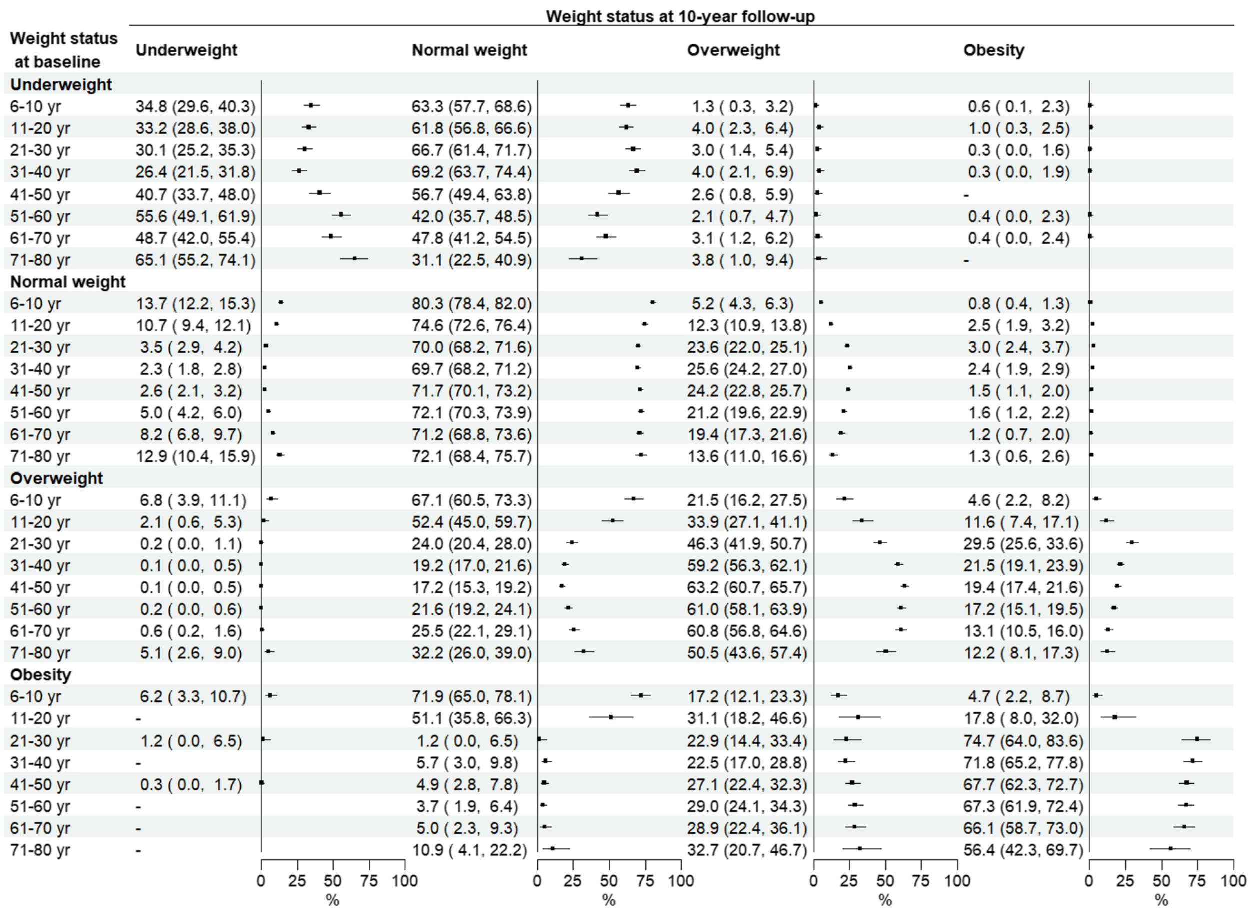

Fig. 3 Maintenance and transition probabilities between weight statuses at 10-year follow-up

individuals with obesity are more likely to maintain their status after entering adulthood. These findings demonstrated the heterogeneity in susceptibilities of maintenance, onset, and resolution of excess weight across different life periods, highlighting the importance of developing age-appropriate approaches for the prevention and intervention of obesity.

Characterizing life-course changes in the prevalence of excess weight is critical for quantifying the age-specific magnitude of health burden but is understudied. Several cross-sectional national population studies have reported age-related changes in the prevalence of obesity during adulthood [11–13], but they cannot estimate the true change over time within individuals. This study used longitudinal data to estimate age-related proportions of weight statuses across the full lifespan and found that the predicted prevalence of obesity decreased from young childhood, bottomed at 20 years, increased thereafter, peaked at around 40 to 55 years, and then decreased slightly. Although the peak age of obesity prevalence differed to some extent from previous national studies, the life-course change patterns were generally similar across studies [26].

From the perspective of prevention, health policies should place more emphasis on individuals who are at a higher risk of obesity development for targeted interventions; yet, few studies have examined the heterogeneity in transitions between weight statuses across different life stages due to a lack of lifespan longitudinal data. In this study, we found that participants aged 21–30 years had higher probabilities of transitioning from normal weight or overweight to obesity than those in other age groups, suggesting that young adulthood is a critical period for obesity development. This period was confirmed by a large-scale cohort study in England showing that young adults aged 18–24 years have the highest absolute and relative risk for transitioning to a higher BMI category than older adult age groups [27]. The highest susceptibility to obesity development occurring in young adulthood could be explained by several biological and behavioral factors. First, obesity can result from a mismatch between energy intake and expenditure. Studies have

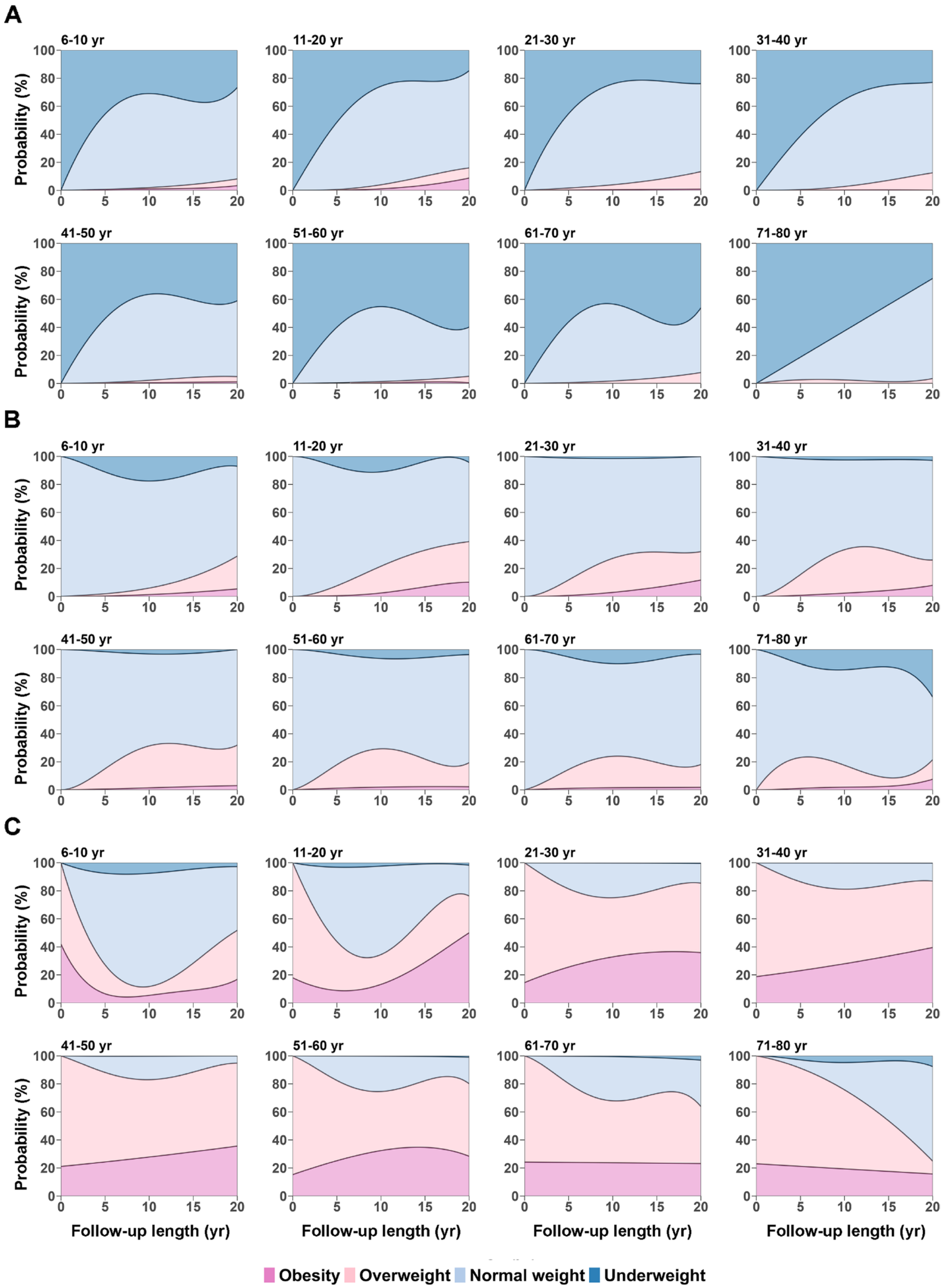

Fig. 4 Maintenance and transition probabilities between weight statuses with follow-up year. **A** Underweight at baseline. **B** Normal weight at baseline. **C** Overweight or obesity at baseline

shown that young adults had lower fat-free mass adjusted energy expenditure compared with children and adolescents [28]. Second, most young adults experience transitions from school to work, often accompanied by the adoption of unhealthy lifestyles including poor dietary habits, lack of physical activity, inadequate sleep, excessive screen time, and high alcohol consumption [29, 30], which contribute to an increased risk of obesity development [31, 32]. Additionally, our data indicated that adults were more likely to maintain obesity and less likely to transition from obesity to normal weight than youths, suggesting that weight loss might become increasingly challenging once individuals reach adulthood. Previous large-scale longitudinal studies have found that weight gain and weight persistence during young adulthood have a profound effect on the risk of cardiovascular disease and mortality in later life [33–35]. Thus, these findings, along with our own, emphasize the importance of primordial prevention in early life before the onset of obesity.

Of interest, we found that individuals with overweight or obesity were more likely to transition to normal weight in childhood and adolescence than in adulthood, suggesting that childhood and adolescence are the most sensitive periods for obesity resolution. However, there is limited literature available for comparison. This finding is important and implies that childhood and adolescence may be the critical periods for effectively addressing obesity through targeted interventions. The finding is consistent with a small family-based intervention study showing that children with obesity showed better weight loss and weight maintenance than their parents with obesity [36], which indicates that obesity intervention in children may be more effective than in adults. The potential explanations for easier obesity resolution in youth include higher resting energy expenditure [28], more physical activity [37], and healthier dietary habits [30] in children and adolescents compared with adults. Further research is needed to understand the mechanisms that may be responsible for differential chances of obesity reversal across different life periods.

Accumulating evidence has shown that children with excess weight have reduced risks of cardiometabolic diseases in adulthood if they reverse to normal weight [8, 9, 38]. Notably, we found that although the likelihood of transitioning to normal weight during childhood and adolescence was relatively high, approximately 45% of children and 65% of adolescents who were overweight are expected to remain overweight or develop obesity after 20 years. Furthermore, about 35% of children and 55% of adolescents who were obese are projected to remain overweight or obese after 20 years. The findings are consistent with many previous studies regarding obesity tracking from childhood to adulthood [14–17]. Therefore, childhood and adolescence appear to be the most critical time window for preventing the onset of obesity in young adulthood, and early intervention strategies targeting lifestyle modifications during these periods could effectively manage and control obesity, thereby reducing the incidence of obesity-associated metabolic disorders and cardiovascular diseases in later life.

We further found that individuals with underweight had exhibited lower BMI tracking correlation and higher probabilities transitioning to other weight statuses compared to those with normal weight, overweight, or obesity across all age groups. Our findings indicate that individuals with underweight are more likely to return to normal weight but are less likely to develop obesity later in life. Specifically, only about 40% of children and adolescents with underweight maintained the status after 20 years, more than half transitioned to normal weight, and about 5% would become overweight or obesity. The results suggest that underweight is a relatively unstable status in the current obesogenic environment. This finding aligns with a previous cohort showing that only 32.5% of underweight children remained underweight after 6 years [16]. It should be noted that individuals who are underweight in childhood and become overweight or obese in later life experience the most rapid weight gain and may confer a greater risk of further health consequences. Thus, individuals transitioning from underweight to obesity should be particularly taken into consideration in future health policies aimed at obesity intervention. Studies have shown that underweight individuals might have higher expected resting energy expenditure [39], different eating dietary habits, and genetic predispositions compared to individuals with obesity [40], which could contribute to lower susceptibility to obesity.

The major strengths of the current study include its population-based cohort design, the large sample size encompassing 23,179 individuals with 95,994 BMI measurements, and an entire age span from 6 to 80 years, which allows us to investigate the differences in maintenance and transition patterns of underweight, normal weight, overweight, and obesity across different life age periods and further identify critical ages for onset and resolution of obesity. However, this study has several limitations to be considered. First, participants in our study were obtained from a selected Chinese sample, and thus the results cannot be generalized to other racial or ethnic groups. Thus, our findings need to be validated in other large-scale populations. Second, the statistical power was insufficient when analyzing data with longer follow-up duration due to a large proportion of dropouts. To enhance the statistical power, we defined longer time windows for 10-year and

20-year analyses, respectively. Third, we were unable to evaluate the influence of birth cohorts, geographical regions, educational levels, and lifestyles on transition patterns of weight statuses because further stratification by these factors exceeds the capabilities of our current sample size. Fourth, BMI does not accurately reflect body fat mass and distribution, and thus the definitions of underweight, overweight, and obesity in the current study may lack precision. Fifth, our results may be influenced by survivor bias, particularly in elderly age groups. Finally, we did not take into consideration the influences of physical exercise, diet, cancer, and other severe chronic diseases on our findings due to a lack of detailed information on these conditions.

Conclusions

In summary, this large-scale longitudinal study examined the heterogeneity in transition patterns of weight statuses across different life stages. The findings indicate that individuals with normal weight are most likely to develop obesity during young adulthood, while those with obesity are most likely to revert to a normal weight status during childhood and adolescence. Further studies are warranted to examine heterogeneity in long-term health consequences of weight status transition at different life stages. The findings emphasize the importance of the development of age-targeted health policies for the prevention and intervention of obesity, thereby mitigating the obesity-related disease burden.

Abbreviations

BMI	Body mass index
CHNS	China Health and Nutrition Survey
AIC	Akaike information criterion

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12916-024-03721-4.

Additional file 1: Supplemental description of methods and results, including Tables S1-S2 and Fig. S1-S10. Table S1. [Characteristics of study participants for 10-year follow-up analysis]. Table S2. [Characteristics of study participants for 20-year follow-up analysis]. Fig. S1. [Flow chart of selection of study participants]. Fig. S2. [Tracking correlation coefficients of BMI by baseline age and weight status in males]. Fig.S3. [Tracking correlation coefficients of BMI by baseline age and weight status in females]. Fig. S4. [Maintenance and transition probabilities between weight statuses at 20-year follow-up]. Fig. S5. [Maintenance and transition probabilities between weight statuses at 10-year follow-up in males]. Fig. S6. [Maintenance and transition probabilities between weight statuses at 10-year follow-up in females]. Fig. S7. [Maintenance and transition probabilities between weight statuses at 20-year follow-up in males]. Fig. S8. [Maintenance and transition probabilities between weight statuses at 20-year follow-up in females]. Fig. S9. [Maintenance and transition probabilities between weight statuses with follow-up year in males]. Fig. S10. [Maintenance and transition probabilities between weight statuses with follow-up year in females].

Acknowledgements

We especially thank the staff members, investigators, and participants who participated in CHNS.

Authors' contributions

Chaonan Gao conducted statistical analyses, interpreted results, and drafted the manuscript. Xin Meng, Wei Liu, and Qianjin Qi edited the manuscript. Yinkun Yan designed the study and edited the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding

This work was supported by was supported by the National Science and Technology Innovation 2030, Major Project—Research on Cancer, Cardiovascular, Respiratory and Metabolic Diseases (Grant No. 2023ZD0508500, 2023ZD0508505), the National Nature Science Foundation of China (Grant No. 82473650, 82073572), and the Beijing Nova Program (Grant No. 20230484467). The funders had no role in the study design, implementation, analysis, or decision to publish or reparation of the manuscript.

Data availability

The data was available at https://www.cpc.unc.edu/projects/china/data/.

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of the University of North Carolina at Chapel Hill, Chapel Hill, North Carolina, United States (No. 07–1963, 6/21/2016) and the Institutional Review Committee of the National Institute for Nutrition and Health, Chinese Center for Disease Control and Prevention, Beijing, China (No. 201524, 8/18/2015).

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 6 June 2024 Accepted: 22 October 2024
Published online: 05 November 2024

References

1. Pan X-F, Wang L, Pan A. Epidemiology and determinants of obesity in China. Lancet Diabete Endocrinol. 2021;9(6):373–92.
2. Thomas FL. Nutrition, obesity, diabetes, and cardiovascular outcomes: a deadly association. Eur Heart J. 2020;41(28):2603–7.
3. Valenzuela PL, Carrera-Bastos P, Castillo-García A, Lieberman DE, Santos-Lozano A, Lucia A. Obesity and the risk of cardiometabolic diseases. Nat Rev Cardiol. 2023;20(7):475–94.
4. Klein S, Amalia G, Hannele Y-J, Philipp ES. Why does obesity cause diabetes? Cell Metab. 2022;34(1):11–20.
5. Bhaskaran K, Dos-Santos-Silva I, A Leon D, Douglas IJ, Smeeth L. Association of BMI with overall and cause-specific mortality: a population-based cohort study of 3.6 million adults in the UK. Lancet Diabete Endocrinol. 2018;6(12):944–53.
6. Buscot M-J, Thomson RJ, Juonala M, Sabin MA, Burgner DP, Lehtimäki T, et al. Distinct child-to-adult body mass index trajectories are associated with different levels of adult cardiometabolic risk. Eur Heart J. 2018;39(24):2263–70.
7. Yan Y, Hou D, Liang Y, Zhao X, Hu Y, Liu J, et al. Tracking body mass index from childhood to adulthood for subclinical cardiovascular diseases at adulthood. J Am Coll Cardiol. 2016;67(8):1006–7.
8. Bjerregaard LG, Jensen BW, Ängquist L, Osler M, Sørensen TIA, Baker JL. Change in overweight from childhood to early adulthood and risk of type 2 diabetes. N Engl J Med. 2018;378(14):1302–12.

9. Juonala M, Magnussen CG, Berenson GS, Venn A, Burns TL, Sabin MA, et al. Childhood adiposity, adult adiposity, and cardiovascular risk factors. N Engl J Med. 2011;365(20):1876–85.
10. Wang Y, Zhao L, Gao L, Pan A, Xue H. Health policy and public health implications of obesity in China. Lancet Diabetes Endocrinol. 2021;9(7):446–61.
11. Chen K, Shen Z, Gu W, Lyu Z, Qi X, Mu Y, et al.: Prevalence of obesity and associated complications in China: a cross-sectional, real-world study in 15.8 million adults. Diabetes Obes Metab 2023; 25(11):3390–99.
12. Hales CM, Carroll MD, Fryar CD, Ogden CL. Prevalence of obesity among adults and youth: United States, 2015–2016. NCHS Data Brief. 2017;288:1–8.
13. Wang L, Zhou B, Zhao Z, Yang L, Zhang M, Jiang Y, et al. Body-mass index and obesity in urban and rural China: findings from consecutive nationally representative surveys during 2004–18. Lancet. 2021;398(10294):53–63.
14. Deshmukh-Taskar P, Nicklas T, Morales M, Yang S-J, Zakeri I, Berenson G. Tracking of overweight status from childhood to young adulthood: the Bogalusa Heart Study. Eur J Clin Nutr. 2006;60(1):48–57.
15. Ryder JR, Jacobs DR Jr, Sinaiko AR, Kornblum AP, Steinberger J. Longitudinal changes in weight status from childhood and adolescence to adulthood. J Pediatr. 2019;214(187–92):e2.
16. Wang Y, Ge K, Popkin BM. Tracking of body mass index from childhood to adolescence: a 6-y follow-up study in China. Am J Clin Nutr. 2000;72(4):1018–24.
17. Ward ZJ, Long MW, Resch SC, Giles CMG, Cradock AL, Gortmaker SL. Simulation of growth trajectories of childhood obesity into adulthood. N Engl J Med. 2017;377(22):2145–53.
18. Simmonds M, Llewellyn A, Owen CG, Woolacott N. Predicting adult obesity from childhood obesity: a systematic review and meta-analysis. Obes Rev. 2016;17(2):95–107.
19. Popkin BM, Du S, Zhai F, Zhang B. Cohort Profile: The China Health and Nutrition Survey–monitoring and understanding socio-economic and health change in China, 1989–2011. Int J Epidemiol. 2010;39(6):1435–40.
20. Zhang B, Zhai F, Du S, Popkin BM. The China health and nutrition survey, 1989–2011. Obes Rev. 2014;15(Suppl 1):2–7.
21. National Health Commission of the People's Republic of China. Screening for overweight and obesity among school-age children and adolescents (WS/T 586-2018). 2018.
22. National Health Commission of the People's Republic of China. Screening standard for malnutrition of school-aged children and adolescents (WS/T 456-2014). 2014.
23. National Health Commission of the People's Republic of China. Criteria of weight for adults (WS/T 456-2014). 2014.
24. Gilmour AR, Anderson RD, Rae AL. The analysis of binomial data by a generalized linear mixed model. Biometrika. 1985;72(3):593–9.
25. Aho K, Derryberry D, Peterson T. Model selection for ecologists: the worldviews of AIC and BIC. Ecology. 2014;95(3):631–6.
26. Opazo Breton M, Gray LA. An age-period-cohort approach to studying long-term trends in obesity and overweight in England (1992–2019). Obesity (Silver Spring). 2023;31(3):823–31.
27. Katsoulis M, Lai AG, Diaz-Ordaz K, Gomes M, Pasea L, Banerjee A, et al. Identifying adults at high-risk for change in weight and BMI in England: a longitudinal, large-scale, population-based cohort study using electronic health records. Lancet Diabetes Endocrinol. 2021;9(10):681–94.
28. Pontzer H, Yamada Y, Sagayama H, Ainslie PN, Andersen LF, Anderson LJ, et al. Daily energy expenditure through the human life course. Science. 2021;373(6556):808–12.
29. Kocevska D, Lysen TS, Dotinga A, Koopman-Verhoeff ME, Luijk M, Antypa N, et al. Sleep characteristics across the lifespan in 1.1 million people from the Netherlands, United Kingdom and United States: a systematic review and meta-analysis. Nat Hum Behav. 2021;5(1):113–22.
30. Frech A. Healthy behavior trajectories between adolescence and young adulthood. Adv Life Course Res. 2012;17(2):59–68.
31. Ushula TW, Mamun A, Darssan D, Wang WYS, Williams GM, Whiting SJ, et al. Dietary patterns and young adult body mass change: a 9-year longitudinal study. Eur J Nutr. 2023;62(4):1657–66.
32. Ushula TW, Lahmann PH, Mamun A, Wang WY, Williams GM, Najman JM. Lifestyle correlates of dietary patterns among young adults: evidence from an Australian birth cohort. Public Health Nutr. 2021;25(8):1–12.
33. Stokes A, Collins JM, Grant BF, Scamuffa RF, Hsiao CW, Johnston SS, et al. Obesity progression between young adulthood and midlife and incident diabetes: a retrospective cohort study of U.S. adults. Diabetes Care. 2018;41(5):1025–31.
34. Chen C, Ye Y, Zhang Y, Pan XF, Pan A. Weight change across adulthood in relation to all cause and cause specific mortality: prospective cohort study. BMJ. 2019;367: l5584.
35. Zheng Y, Manson JE, Yuan C, Liang MH, Grodstein F, Stampfer MJ, et al. Associations of weight gain from early to middle adulthood with major health outcomes later in life. JAMA. 2017;318(3):255–69.
36. Epstein LH, Valoski AM, Kalarchian MA, McCurley J. Do children lose and maintain weight easier than adults: a comparison of child and parent weight changes from six months to ten years. Obes Res. 1995;3(5):411–7.
37. Lounassalo I, Salin K, Kankaanpää A, Hirvensalo M, Palomäki S, Tolvanen A, et al. Distinct trajectories of physical activity and related factors during the life course in the general population: a systematic review. BMC Public Health. 2019;19(1):271.
38. Tirosh A, Shai I, Afek A, Dubnov-Raz G, Ayalon N, Gordon B, et al. Adolescent BMI trajectory and risk of diabetes versus coronary disease. N Engl J Med. 2011;364(14):1315–25.
39. Hu S, Zhang X, Stamatiou M, Hambly C, Huang Y, Ma J, et al. Higher than predicted resting energy expenditure and lower physical activity in healthy underweight Chinese adults. Cell Metab. 2022;34(10):1413–5.
40. Riveros-McKay F, Mistry V, Bounds R, Hendricks A, Keogh JM, Thomas H, et al. Genetic architecture of human thinness compared to severe obesity. PLoS Genet. 2019;15(1):e1007603.

Publisher's Note