BMI Trajectories Associated With Resolution of Elevated Youth BMI and Incident Adult Obesity

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BACKGROUND AND OBJECTIVES: Youth with high BMI who become nonobese adults have the same cardiovascular risk factor burden as those who were never obese. However, the early-life BMI trajectories for overweight or obese youth who avoid becoming obese adults have not been described. We aimed to determine and compare the young-childhood BMI trajectories of participants according to their BMI status in youth and adulthood.

METHODS: Bayesian hierarchical piecewise regression modeling was used to analyze the BMI trajectories of 2717 young adults who had up to 8 measures of BMI from childhood (ages 3–18 years) to adulthood (ages 34–49 years).

RESULTS: Compared with those with persistently high BMI, those who resolved their high youth BMI by adulthood had lower average BMI at age 6 years and slower rates of BMI change from young childhood. In addition, their BMI levels started to plateau at 16 years old for females and 21 years old for males, whereas the BMI of those whose high BMI persisted did not stabilize until 25 years old for male subjects and 27 years for female subjects. Compared with those youth who were not overweight or obese and who remained nonobese in adulthood, those who developed obesity had a higher BMI rate of change from 6 years old, and their BMI continued to increase linearly until age 30 years.

CONCLUSIONS: Efforts to alter BMI trajectories for adult obesity should ideally commence before age 6 years. The natural resolution of high BMI starts in adolescence for males and early adulthood for females, suggesting a critical window for secondary prevention.
Overweight and obesity in childhood and adolescence (herein termed youth) is associated with adverse cardiometabolic profiles that tend to persist into adulthood.\textsuperscript{1–6} In particular, childhood BMI predicts adulthood obesity\textsuperscript{7,8} and other long-term health outcomes, including cardiovascular disease (CVD) and type 2 diabetes mellitus.\textsuperscript{5,9–16} Because obesity is difficult to reverse once established,\textsuperscript{9,17–19} many studies highlight the importance of the formative years in the development of lifelong BMI trajectories.\textsuperscript{20–23} Yet, the dynamic processes that drive the development of childhood overweight and obesity and the tracking or potential resolution of high BMI from childhood into adulthood are not completely understood.\textsuperscript{5} Although recent longitudinal studies have investigated BMI trajectories in infancy, early childhood,\textsuperscript{9,12,24–26} and from childhood to adolescence or young adulthood,\textsuperscript{23,27–30} few long-term observational studies have available data to examine BMI trajectories from early childhood to midadulthood. Because excess weight in adolescence is known to have a strong, adverse impact on multiple cardiovascular risk factors, the importance of primary prevention early in life has been advocated.\textsuperscript{31,32} However, although observational and intervention studies have highlighted the potential benefits of improving BMI levels in obese children and adolescents,\textsuperscript{33,34} little is known about the BMI pathways of those who manage to overcome obesity between youth and adulthood. Such data may identify critical windows for intervention.

A recent multicohort study highlighted the potential health impact of improving weight status across the life course by reporting that overweight or obese youth who were not obese in adulthood had similar risks for type 2 diabetes mellitus, dyslipidemia, preclinical atherosclerosis, and hypertension compared with those who were never obese.\textsuperscript{13} However, a lack of complete serial data in some of these cohorts precluded the accurate description and analysis of the early-life BMI trajectories of participants who resolved their overweight or obesity by adulthood and of those who developed incident obesity from a normal BMI. Moreover, data from only 2 time points did not provide information as to when in the period between youth and midadulthood that the change in BMI status occurred.\textsuperscript{13}

Therefore, we analyzed BMI data across the life course in the Cardiovascular Risk in Young Finns Study (YFS)\textsuperscript{35} using Bayesian hierarchical piecewise regression.\textsuperscript{36} Our primary aim was to model individual trajectories of BMI from youth to adulthood and investigate differences in trajectories across 4 a priori–defined groups based on BMI status (assessed once in youth and once in adulthood).\textsuperscript{13,37}

**METHODS**

**Study Sample and Design**

The YFS is a population-based prospective cohort that commenced in Finland in 1980 to investigate cardiovascular risk factors and their determinants from youth to adulthood.\textsuperscript{35} The YFS participants are all of white, Northern European ancestry. The current analyses focus on serial BMI measurements taken on up to 8 occasions over 31 years (in 1980, 1983, 1986, 1989, 1992, 2001, 2007, and 2011). We included 2717 YFS participants (1252 male, 1465 female) from 6 different birth cohorts (1962, 1965, 1968, 1971, 1974, and 1977) who had a youth BMI measure at baseline (in 1980, age 3–18 years) and at least 1 adult BMI measure taken 21, 27, or 31 years later (in 2001, 2007, or 2011) (Supplemental Table 5). For the calculations of BMI, standing height was measured to the nearest 0.5 cm by using a wall-mounted seca anthropometer with the participant in bare feet. Weight was measured with participants in light clothes without shoes by using a digital seca weighing scale that recorded to the nearest 0.1 kg. On average, there were 5.25 nonmissing BMI measures per participant (ranging from 3 to 8 individual measures). Participants or their parents provided informed consent, and the study was approved by the local ethics committees in accordance with the Declaration of Helsinki.

**Definition of BMI Status Groups**

In keeping with previous studies,\textsuperscript{13} youth overweight and obesity were defined as using international age- and sex-specific BMI cutoffs for youth aged 6 to 18 years\textsuperscript{38} and adult weight status was defined as overweight for a BMI $\geq 25$ and as obese for a BMI $\geq 30$ for participants aged 21 years and older. On the basis of their movement from 1 weight status category to another between the baseline examination (in 1980) and their most recent follow-up in adulthood, each participant was assigned to 1 of 4 possible BMI status groups (Table 1): Group I had normal BMI in youth and were nonobese in adulthood (reference group), Group II were overweight or obese as youth but nonobese as adults (high-BMI persisting group), Group III were overweight or obese as youth and obese in adulthood (high-BMI resolving group), and Group IV had normal BMI in youth but became obese as adults (incident obese group).

**Statistical Analyses**

Individual BMI trajectories between ages 6 and 49 years were modeled by using a hierarchical piecewise growth modeling approach with a linear-linear functional form and random change points (CPs). One of the advantages of this approach is that the piecewise specification of the
within-person (Level 1) model maps onto known, key aspects of the BMI development between 6 and 49 years old. Indeed, it can be modeled as a 2-phased process by using 2 distinct linear segments joining at a CP that represents the age at which individuals transition to a slower BMI growth rate (which usually happens at the end of puberty for each sex). The Bayesian implementation of this model allows the estimation of between-person heterogeneity (ie, random effects) in all 4 parameters describing individual BMI change across the life course: the baseline BMI level, the yearly rate of change in BMI in youth (youth slope $S_1$), the age at the CP, and the yearly rate of change in BMI in adulthood (adult slope $S_2$) (see Supplemental Methods 1).

This allows for descriptions of group-specific prototypical growth curves showing how the BMI developed on average in each group of interest. Technical aspects of this modeling approach, including detailed model parameterization and Bayesian implementation, are described extensively. Specifically, in the current application, parameters describing sex- and obesity-specific, average BMI trajectories are retrieved by sampling the posterior distribution of the 4 growth parameters, and the between-group differences in these parameters were investigated by using the posterior distributions for the credible differences between the curve parameters for the different groups. Because the YFS participants were born up to 15 years apart, we simultaneously adjusted for any potential intercohort variability in BMI development between ages 6 and 49 years by including the initial age (ie, a participant’s age in 1980) as a continuous predictor of each growth parameter. The Bayesian hierarchical piecewise growth curve model analyses were estimated via Markov chain Monte Carlo sampling by using the Rjags and R2jags statistical packages in R. The Bayesian model code used for model fitting in this article, including likelihood formulation and previous specification, is provided in Supplemental Methods 1.

**RESULTS**

**Study Cohort**

BMI records ($N = 15,748$) from 2717 participants ($n = 1252; 46\%$ male) from up to 8 time points were used in the analyses. Compared with the YFS subjects included in the multicenter study, there were an additional 77 YFS participants ($n = 37; 48%$ male) in the current analysis, with data from follow-up in 2011. The number and relative proportion of participants in each of the 4 adiposity status groups were reported in Table 2. The proportion of youth overweight or obesity was 8.4% at baseline and higher among male subjects on average (9.1% vs. 6.7%; Supplemental Table 9). Of participants, 19.8% were obese as adults at their latest assessment. Participants were on average 24.5 years old (there were no sex differences; independent Welsh corrected $t$ test, $t = -1.5; df = 13,835; P = .12$; Supplemental Table 10).

However, differences in age between the 4 obesity groups were significant (all $P < .001$), with participants who resolved their high BMI in youth (Group II) being slightly younger than participants who became obese (Group IV) and those who remained nonobese (Group I; Supplemental Table 10). These differences were small, however, suggesting adequate representation of all birth cohorts in all adiposity subgroups.

**BMI Trajectories in the 4 BMI Groups**

Data exploration suggested that there was significant variability by sex in the BMI trajectories among the 4 groups of interest (see Supplemental Methods 1 for more details). Therefore, models were adjusted to give sex-specific BMI trajectory parameters within each of the 4 groups. The first 2 columns of Tables 3 and 4 show the estimated mean growth parameters for each sex and obesity group and describe the average prototypical BMI trajectories between 6 and 49 years of age represented in Figs 1 and 2. For each sex, the differences in trajectory parameters between the reference and incident obese participants (Group I versus Group IV, Table 3) and between resolving and persistent obese participants (Group II versus Group III; Table 4)

| Table 1 Summary of the 4 BMI Status Groups Considered Throughout This Study |
|---------------------------------|---------------|---------------|-----------------|-----------------|
| Childhood BMI Status | Adulthood BMI Status | Group | BMI Status Group |
| Normal wt | Nonobese (normal or overweight) | 1 | Reference group |
| Overweight or obese | Obese | 4 | Incident obese |
| Overweight or obese | Nonobese (normal or overweight) | 2 | High-BMI resolving |
| Overweight or obese | Obese | 3 | High-BMI persisting |

$^a$ Childhood BMI status was assessed at baseline in 1980 for each included participant. The age range at baseline is 6–18 years. $^b$ Adulthood BMI status was assessed at the latest follow-up for each participant up to 31 years later. The age range at adult BMI assessment is 34–49 years.

| Table 2 Number of Participants (%) in Each Obese Status Group Stratified by Sex |
|---------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Sex | Group I (Reference), $n$ (%) | Group II (High-BMI Resolving), $n$ (%) | Group III (High-BMI Persisting), $n$ (%) | Group IV (Incident Obese), $n$ (%) | Total, $n$ |
| Male | 961 (76.7) | 35 (2.8) | 73 (5.8) | 183 (14.7) | 1,252 |
| Female | 1124 (76.7) | 58 (3.9) | 82 (4.2) | 221 (15.1) | 1,466 |
| Total | 2,085 (76.7) | 93 (5.4) | 155 (4.9) | 404 (14.9) | 2,717 |
are all significant (see Supplemental Tables 8 and 10 for 95% credible intervals [CIs]), suggesting these groups are different in all aspects of their BMI development (initial levels at age 6 years, childhood growth rate, age at transition, and adult growth rate). The significance and magnitude of sex differences in the means of the 4 growth parameters for each BMI group are shown in the Supplemental Information (see also Supplemental Table 8).

Compared with those who remained nonobese as adults (Group I), participants who developed obesity in adulthood (Group IV) had a 0.8-higher average BMI at age 6 years (SD = 0.3) for male subjects and for female subjects (SD = 0.4) (Fig 1). Similarly, among overweight or obese youth and compared with those who remained obese in adulthood, those who were not obese in adulthood (Group II) had average initial BMI levels that were 2.0 lower for male subjects (SD = 0.6) and 3.4 lower for female subjects (SD = 0.8). Those who had high BMI in youth but avoided becoming obese as adults (Group II) transitioned to an almost-null BMI change rate in adulthood earlier than those who had persistent obesity (Group III; 3.6 and 10.1 years sooner for male and female subjects, respectively; Fig 2 and Table 4), leading to a leveling off in their BMI trajectory. It appears that participants who improved their high youth BMI (Group II) reached this transition in their BMI trajectories sooner than those who were of normal weight in youth and were nonobese in adulthood. That is, they reached their CP at 16.1 (SD = 1.4) years old for female subjects and 21.4 (SD = 1.7) years old for male subjects versus 17.2 years old (SD = 0.3) and 24.1 years old (SD = 0.4) in Group I (Tables 3 and 4). However, although they became nonobese, they remained of average overweight or were borderline overweight in adulthood (ie, average BMI levels in Group II were close to or >25 from ~35 years of age, especially for male participants [Fig 2]). In contrast, male and female subjects in the incident obese group (Group IV) and the persisting obese group (Group III) reached their adult BMI rate at the same age (~30 and ~25 years, respectively; Tables 3 and 4).

Compared with the reference group (Group I), participants who were of normal weight in youth but became obese as adults (Group IV) had significantly greater BMI rates in youth and in adulthood past their CPs (ie, steeper slopes [S1 and S2]; Table 3). Compared with the reference group (Group I), the average youth BMI rate of incident obese participants increased by 17%
in male subjects and 14% in female subjects, and they remained on this rapidly increasing, linear trajectory until ∼30 years old. In this group, the female subjects who became obese had higher BMI levels than male subjects by midadulthood because they had significantly steeper adult BMI slopes ($S_2$) compared with male subjects (Fig 1 and Table 3).

The between-subject variability in the trajectory parameters (especially the age at transition between the youth and adult BMI rate) not accounted for by belonging to 1 of the 8 a priori–defined, sex-by-BMI groups is relatively large ($\sigma^2_{CP} = 25$, Supplemental Table 13). This suggests underlying variability in the sample in different aspects of the BMI change over time within each considered group, particularly in the age at which participants transition to their adult BMI growth rates.

When adjusting for birth cohort in the trajectory model, we did not detect any systematic variation in the BMI trajectory parameters as a function of birth year (Supplemental Table 14), suggesting that the 6 birth cohorts in the YFS sample are relatively homogenous in their developmental trajectories of BMI.

**DISCUSSION**

Building on findings from a 4-cohort study in which researchers showed that normalizing high BMI by adulthood was associated with a reduction in cardiovascular risk, we took advantage of the 31 years of follow-up in the YFS cohort to characterize (for the first time) the change in BMI from age 6 to 49 years in different BMI groups and examine the timing of normalization or the incidence of elevated BMI in the YFS cohort. To better understand the BMI development in those who normalized their CVD risk by overcoming elevated BMI levels in youth and in those who increased their CVD risk by becoming obese adults, we used Bayesian hierarchical piecewise regression, an advanced multilevel growth curve modeling approach that allows us to estimate biologically meaningful and interpretable growth coefficients as well as between-person variability in key aspects of the BMI development across the life course.\(^{36}\)

Compared with the reference group, which included those who were not obese in youth or adulthood (Group I), the BMI of normal weight youth who developed obesity in adulthood was higher from age 6 years and increased significantly faster from youth until young adulthood (∼30 years), confirming that the roots...
of incident adult obesity lie in BMI trajectories from early youth (beginning before age 6 years) and that maintaining normal BMI rates in youth is crucial to preventing later overweight and obesity. \(^{32}\) These findings are consistent with previous studies that reported that the majority of excess body weight in children who develop obesity was often gained before age 5 years, \(^{9,44-47}\) and these individuals had an increased weight-for-height velocity after age 3 years that resulted in a crossing of higher BMI percentiles. \(^{45,47-49}\)

The group of participants found to have reversed their adult CVD risk in the previous study, \(^{13}\) which included those who overcame high youth BMI by adulthood (Group II), had lower average BMI levels from age 6 years and slower yearly increases in BMI in youth compared with participants who remained obese as adults (Group III). These findings are in line with those of other studies, which advise that efforts to reverse adverse BMI trajectories should ideally begin in early life, which is in line with current international pediatric guidelines and recommendations for the evaluation, prevention, and management of obesity. \(^{50-54}\) However, the transitioning to an almost-null BMI growth rate for these participants at \(\sim 16\) years old for female subjects and \(21\) years for male subjects suggests they corrected their adverse weight status by plateauing in their BMI trajectories before the end of adolescence, the period in which the transition to a slower increasing adult BMI rate naturally occurs in normal weight participants. In contrast, the BMI of those who remained obese into adulthood (Group III) continued to increase linearly at the same rate until they were \(\sim 25\) years old. This is the first study to describe the natural resolution of high youth BMI, and our findings suggest that puberty is a sensitive window for the secondary prevention of obesity. Secondary interventions targeting the control of obesity progression in overweight older youth (ie, slowing down the increase in BMI yearly rates to stabilize weight) \(^{50}\) may contribute to reducing the incidence of adult obesity.

Additionally, we found that participants with persistently high BMI (Group III) reached higher asymptotic levels of BMI compared with incident obese participants (Group IV). This is consistent with the established tracking of adverse BMI from youth to adulthood; unresolved obesity generally gets worse with age. \(^{1,2,4,55}\)

![Average age-related BMI trajectories](image)
The posterior standard deviations (PSDs) reported along with the marginal posterior means of each growth parameter in Tables 3 and 4 quantify the uncertainty around the point estimate for each parameter (similar to an SD around a regression coefficient in the classic statistical framework). Model validation plots suggest that the estimated trajectory parameters provided an adequate representation of the BMI age curve for all considered groups from age 6 to 49 years despite a slightly larger PSD in the growth parameters estimated for Groups II and III compared with those obtained for the reference group (Group I) and the incident obese group (Group IV). Because all 95% CIs remained significant (Tables 3 and 4 and Supplemental Table 11), we are confident that the relatively small sample size in some of the sex-by-BMI status groups did not overly affect the precision of growth parameter estimates.

Enhanced knowledge of the dynamics of BMI change across the life course, especially the development of pathologic versus normal age-related BMI trajectories, may help guide clinical and public health practice by suggesting critical and sensitive windows for intervention targeted at reducing the incidence of adult obesity with the aim of halting the progression of existing obesity.26,56,57

This is the first study in which researchers describe BMI patterns from early childhood to midadulthood in 4 groups of clinical interest. A better understanding of the trajectories of those who develop obesity or those who had high BMI in childhood but did not become obese in adulthood is particularly important from a public health perspective. This study has some limitations. Despite a high prevalence of adult overweight in our sample, similar to the previous multicenter study, we collapsed overweight and normal weight adults into a single nonobese adult status to optimize the number of participants per category.13 This classification of study participants into 4 groups prevented the discrimination of CVD risk between incident overweight and truly normative BMI trajectories. As a result, the average age-BMI curve we estimated for the reference group (Group I) in this study reached borderline overweight BMI levels (BMI ≥25) in midadulthood along with relatively large estimates of the within-group residual error. It has been noted that analyses of different combinations of BMI groups (for example, obese versus nonobese) characterized over the life course can result in a loss of information because of discrete categorization,58,59 and using dichotomous measures of obesity and overweight can create misclassification bias, especially at young ages.9 To overcome these potential issues, future researchers should thus consider alternative approaches to identify clusters of participants who share similar BMI profiles across all existing measures rather than at 2 individual assessments. These may provide additional insight into the association between life course adiposity trajectories and later CVD risk factors.40,60

CONCLUSIONS

Our study takes advantage of 31 years of follow-up data in the YFS and provides insights into the timing of potential BMI differences in young childhood between those who do or do not maintain high BMI from youth to midadulthood. Our findings suggest that efforts to influence BMI trajectories that lead to adult obesity should begin early in life, ideally before age 6 years. In addition, the natural resolution of high youth BMI levels begins in adolescence for male subjects and early adulthood for female subjects in this cohort, suggesting a critical window for secondary prevention before these stages of the life course.

ABBREVIATIONS

CI: credible interval
CP: change point
CVD: cardiovascular disease
PSD: posterior standard deviation
S<sub>1</sub>: youth slope
S<sub>2</sub>: adult slope
YFS: Young Finns Study

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