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Childhood Obesity Dynamics and Risk of Heart Disease and Diabetes in Adulthood: Evidence from a U.S. Synthetic Cohort

Sarah Qabazard¹, Natalia E Poveda Rey², Solveig A Cunningham^{3,4}

¹ Nutrition and Health Sciences Program, Laney Graduate School, Emory University, Atlanta, United States

² Department of Nutrition and Biochemistry, Faculty of Sciences, Pontificia Universidad Javeriana, Bogotá, Colombia

³ Hubert Department of Global Health, Emory University, Atlanta, United States

⁴ Netherlands Interdisciplinary Demographic Institute, The Hague, Netherlands

ABSTRACT

Background: Childhood obesity, which is rising across middle- and upper-income countries, has long-term health consequences. This study examines how the timing, duration, and intensity of obesity in childhood and adolescence are associated with adult heart disease and diabetes using a longitudinal synthetic cohort spanning two decades of follow-up.

Methods: We used synthetic cohort methods to follow a nationally representative group of U.S. children who were in kindergarten in 1998-1999 (born in 1991-1994) from ages 4 to 42. Data were from the Early Childhood Longitudinal Study, linked with the National Longitudinal Survey of Youth, after matching individuals of same sex and similar weight trajectories at overlapping ages. BMI trajectories were tracked across mid-childhood (4-9 years), early-adolescence (10-14), and late adolescence (15-19 years). Obesity dynamics were defined using indicators of age of onset, obesity duration, and excess BMI-years (composite measure of intensity and duration). Physician-diagnosed heart disease and diabetes were measured at ages 30-40. Survey-weighted logistic regression models estimated associations, adjusting for sex, race/ethnicity, and urbanicity.

Results: Longer duration of obesity in mid-childhood was associated with higher odds of adult heart disease (AOR = 1.33; 95% CI: 1.11-1.59), while duration in adolescence (15-19 years), was linked to greater diabetes risk, with each additional year of obesity increasing

odds by 29% (AOR = 1.29; 95% CI: 1.09-1.53). Excess BMI was positively associated with diabetes during early adolescence.

Conclusion: Early and sustained obesity, particularly during adolescence, confers elevated risk for adult cardiometabolic disease. Preventing prolonged obesity exposure in youth may reduce future diabetes and heart disease.

INTRODUCTION

Childhood obesity is a major global health concern, affecting nearly one in five children and adolescents in the United States (1, 2). Its growing prevalence has serious public health implications, as obesity in early life is linked to a higher risk of type 2 diabetes, cardiovascular disease, and poorer quality of life in adulthood (3, 4, 5, 6). While these associations are well established, most existing studies rely on single body mass index (BMI) measurements or cross-sectional data, providing limited insight into how excess weight develops and persists throughout growth and life (7, 8, 9).

A life-course perspective is needed to understand how body weight trajectories influence later health. Evidence suggests that not only the presence but also the timing and persistence of obesity are critical for shaping long-term cardiometabolic health (9, 10). Early and prolonged exposure to excess adiposity may have lasting metabolic effects, while later or short-term exposure might be less detrimental. Yet, few studies have quantified these dynamics using nationally representative data or assessed how developmental differences in obesity contribute to adult disease risk.

This study builds on that gap by examining obesity as a dynamic exposure that evolves through distinct stages of growth. By capturing variation in obesity onset, duration, and intensity, this study can provide new evidence on how early-life weight trajectories relate to adult cardiometabolic risk and offers insight into potential windows for prevention and intervention.

DATA & METHODS

Data

This study utilized harmonized, nationally representative longitudinal data to examine how patterns of childhood and adolescent obesity dynamics relate to adult cardiometabolic risk. Data were drawn from two U.S. cohorts: the Early Childhood Longitudinal Study, Kindergarten Class of 1998-1999 (ECLS98), which follow children from ages 5-14 years with measured anthropometry, and the National Longitudinal Survey of Youth 1997 (NLSY97), which follow individuals aged 12-16 years in 1997 through adulthood, capturing repeated measures of self-reported height, weight, and chronic disease conditions. In ECLS98,

height and weight were measured by trained staff using a ShorrBoard and a digital scale. In NLSY97, weight was self-reported in each round and height in rounds 1–15. Individuals from the two datasets were matched and linked based on sex and similar weight trajectories at overlapping ages to construct a synthetic life-course cohort, enabling the creation of BMI trajectories spanning ages 4 to 42 years.

Construction of synthetic cohort

Synthetic cohort construction employed a modified hot-deck matching approach in which individuals from ECLS98 served as recipients and NLSY97 participants as donors. Matching was based on sex and individual BMI trajectories, defined by mean BMI at the start of the study and mean BMI over time across the overlapping ages of 12–16 years in the two datasets. A 1:1 donor-recipient ratio was implemented to preserve the binary outcome interpretability, ensuring that each ECLS98 child was linked to a single NLSY97 individual with a comparable BMI trajectory. Details and assumptions of the synthetic cohort can be found elsewhere (11). This approach linked adult outcomes obtained from the NLSY97 dataset, self-reported physician diagnoses of heart disease and diabetes measured at ages 30–40 years, to early-life obesity patterns derived from ECLS98. By integrating these outcomes into the matched synthetic cohort, we established a continuous life-course dataset that connects childhood and adolescent obesity dynamics with adult cardiometabolic health.

Childhood obesity dynamics exposures and adult cardiometabolic indicators

Obesity status was according to the CDC age- and sex- specific growth reference percentiles, with obesity classified as a BMI at or above 95th percentile. To capture developmental specificity, all analyses were structured around three distinct developmental periods: mid-childhood (ages 4-9), early-adolescence (ages 10-14), and late-adolescence (ages 15-19). Within each period, we derived indicators characterizing multiple obesity dynamics exposures: (1) age of onset, defined as the earliest age at which obesity occurred; (2) duration of obesity, defined as the total number of years with obesity within the window; and (3) excess BMI-years, a composite measure of duration in years and the mean number of BMI units above the BMI threshold for obesity. Analytic samples for each period were restricted to participants with a minimum of three valid BMI observations to ensure sufficient longitudinal data for estimating individual trajectories. Heart disease and diabetes were obtained from the NLSY97 dataset and coded as binary indicators based on self-reported physician diagnosis at ages 30-40 years.

Statistical analysis

All analysis incorporated survey design adjustments, including sampling weights, strata, and primary sampling units, to account for the complex survey design of the source dataset: ECLS98. Associations between obesity dynamics and adult health indicators were estimated using survey-weighted logistic regression models, adjusting for sex, race/ethnicity, urbanicity and adult obesity. All statistical analysis were conducted in R (version 4.1.2).

PRELIMINARY RESULTS

Synthetic cohort characteristics

The survey-adjusted sociodemographic characteristics of the analytic sample, representing a nationally population-representative cohort of U.S. children who entered kindergarten in 1998-1999, are presented in Table 1. The cohort spans ages 4-42 years with a sample size of 10,210. Approximately half of the participants were female, 70% identified as White or Other race, and majority went to kindergartens in urban areas.

Obesity dynamics

Table 2 summarizes the survey-adjusted estimates of obesity dynamics across mid-childhood (4-9 years), early adolescence (10-14 years), and late adolescence (15-19 years) in the synthetic cohort. Mean baseline body mass index (BMI) increased from 16.3 kg/m² (4-9 years) to 23.8 kg/m² (15-19 years). The prevalence of obesity rose from 11.6% mid-childhood to 21% in adolescence. In each developmental period, the mean age of obesity onset was 7.5, 12.2, and 17.9 years, respectively. New incident cases peaked in mid-childhood (10.9%) and declined in early adolescence (4.9%).

The duration of obesity showed a consistent pattern of accumulation with age, increasing from a mean of 0.57 years (95% CI: 0.54, 0.60) in mid-childhood to 0.83 years (95% CI: 0.80, 0.87) during adolescence. Among children classified as having obesity at baseline, the average duration of obesity reached 3.23 years (mid-childhood), 3.43 years (early adolescence), and 3.59 years (late adolescence), corresponding to nearly the entire follow-up period within each developmental window. This was also reflected among participants who already had obesity at the start of each developmental period, more than 85% of their total observed time in that period was spent remaining with obesity.

Childhood obesity dynamics associations with heart disease at age 30-40 years

Across developmental periods, longer duration of obesity in mid-childhood (ages 4-9 years) was significantly related to higher odds of heart disease in adulthood (AOR = 1.33; 95% CI: 1.11-1.59), even after adjusting for demographic factors. No significant associations were

observed for obesity duration during adolescence. Excess BMI-years showed a modest negative association in mid-childhood (AOR = 0.94; 95% CI: 0.89-0.98), but this was attenuated in fully adjusted models. Overall, obesity sustained during early childhood appeared more strongly associated with adult heart disease than exposures beginning later, underscoring early childhood as a sensitive period for cardiovascular risk accumulation.

Childhood obesity dynamics associations with diabetes at age 30-40 years

Longer duration of obesity exposure was strongly associated with adult diabetes, particularly during adolescence. Each additional year of obesity in late adolescence (ages 15-19 years) increased diabetes odds by 29% (AOR = 1.29; 95% CI: 1.09-1.53), and duration during early adolescence (10-14 years) was also significant (AOR = 1.20; 95% CI: 1.02-1.41). Cumulative excess BMI, reflecting both intensity and duration of exposure, was similarly associated with higher diabetes risk in early adolescence (AOR = 1.04; 95% CI: 1.00-1.08). Associations during mid-childhood were weaker and not statistically significant. Adult obesity remained an independent correlate (AOR = 1.99; 95% CI: 1.23-3.22), but early-life duration of obesity retained significance, suggesting adolescence as a critical window for diabetes prevention.

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LIST OF TABLES

Table 1. Survey-adjusted sociodemographic characteristics of participants in the synthetic cohort (1998–1999 U.S. kindergarten birth cohort) (n=10,210)

Characteristics	
Cohort age range (years)	4 - 42
Gender, % (95% CI)	
Male	51.1 (49.9, 52.2)
Female	48.9 (47.8, 50.1)
Race/ Ethnicity, % (95% CI)	
Hispanic	19.8 (17.7, 21.8)
Black	12.2 (10.0, 14.3)
White/ Other	68.1 (65.5, 70.6)
Urbanicity, % (95% CI)	
Rural	25.9 (21.8, 30.0)
Urban	74.1 (70.0, 78.2)

Table 2. Childhood and Adolescent Obesity Dynamics in the 1998–1999 U.S. Kindergarten Birth Cohort (Synthetic Cohort 1:1) (n=10210)

Obesity Dynamics	Mid-childhood 4-9 years	Early-adolescence 10-14 years	Late-adolescence 15-19 years
Baseline BMI	16.3 (16.3, 16.4)	20.05 (19.94, 20.16)	23.83 (23.68, 23.97)
Baseline weight status, n (%)			
Underweight	3.8 (3.2, 4.4)	1.61 (1.24, 1.98)	1.66 (1.30, 2.01)
Healthy weight	69.8 (68.8, 70.9)	58.39 (57.08, 59.70)	58.43 (57.28, 59.57)
Overweight	14.8 (14.0, 15.6)	18.71 (17.82, 19.59)	19.27 (18.46, 20.08)
Obesity	11.6 (10.9, 12.3)	21.29 (20.32, 22.26)	20.65 (19.67, 21.63)
Age of obesity onset (years)	7.46 (0.04)	12.20 (0.06)	17.93 (0.04)
Duration of obesity (years)			
Total	0.57 (0.54, 0.60)	0.83 (0.79, 0.87)	0.83 (0.80, 0.87)
Underweight	0.06 (0.03, 0.10)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)
Healthy weight	0.10 (0.09, 0.12)	0.02 (0.01, 0.02)	0.01 (0.01, 0.01)
Overweight	0.84 (0.76, 0.91)	0.47 (0.42, 0.53)	0.45 (0.41, 0.49)
Obesity	3.23 (3.16, 3.31)	3.43 (3.38, 3.48)	3.59 (3.55, 3.63)
Excess BMI-Years			
Total	1.73 (1.61, 1.85)	3.35 (3.12, 3.58)	4.27 (3.96, 4.58)
Underweight	0.09 (0.04, 0.15)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)
Healthy weight	0.17 (0.14, 0.21)	0.02 (0.01, 0.03)	0.02 (0.01, 0.02)
Overweight	1.30 (1.11, 1.49)	0.60 (0.50, 0.70)	0.54 (0.47, 0.61)
Obesity	12.21 (11.56, 12.87)	15.13 (14.41, 15.86)	20.12 (19.07, 21.17)

Note: Data are presented as weighted mean (95% CI) or individual-level mean (SE); SE: standard error. Age of obesity onset: The earliest age at which an individual was first classified as obese (BMI z-score ≥ 95 th percentile) within each developmental period. Duration of obesity: Total number of years classified as obese within the developmental window. Excess BMI-years: Cumulative excess BMI (above the obesity threshold) across the developmental period, integrating both intensity and duration of obesity.

Table 3. Association between childhood obesity dynamics and adult heart disease (age 30-40 years) across developmental periods

Outcome: Heart								
Predictors	Model 1		Model 2		Model 3		Model 4	
	AOR	95% CI	AOR	95% CI	AOR	95% CI	AOR	95% CI
Male	1.07	(0.73, 1.57)	1.09	(0.74, 1.60)	1.11	(0.76, 1.62)	1.05	(0.71, 1.54)
Hispanic	0.95	(0.64, 1.42)	0.97	(0.65, 1.46)	1.00	(0.66, 1.52)	0.93	(0.62, 1.40)
Black	0.83	(0.48, 1.43)	0.85	(0.49, 1.48)	0.88	(0.51, 1.53)	0.85	(0.49, 1.48)
Urban	1.60*	(1.07, 2.39)	1.60*	(1.08, 2.37)	1.55*	(1.02, 2.34)	1.60*	(1.06, 2.43)
Mid-Childhood (4-9 yrs)								
Baseline BMI (mean)	1.02	(0.89, 1.17)					1.02	(0.89, 1.17)
<i>Duration of obesity (years)</i>	1.33***	(1.11, 1.59)					1.36**	(1.09, 1.71)
Excess BMI-Years	0.94**	(0.89, 0.98)					0.96	(0.89, 1.04)
Early Adolescence (10-14 yrs)								
Baseline BMI (mean)			1.01	(0.94, 1.08)				
<i>Duration years (years)</i>			1.13	(0.96, 1.33)			0.99	(0.82, 1.19)
Excess BMI			0.98	(0.96, 1.01)			0.96	(0.91, 1.02)
Late Adolescence (15-19 yrs)								
Baseline BMI (mean)					0.91*	(0.84, 0.98)		
<i>Duration years (years)</i>					1.19	(0.96, 1.49)	0.98	(0.81, 1.20)
Excess BMI					1.02	(1.00, 1.05)	1.02	(0.99, 1.05)
Adult Obesity	0.82	(0.56, 1.22)	0.85	(0.57, 1.26)	1.10	(0.71, 1.71)	0.82	(0.54, 1.24)

Note: p-value: * <0.05, **<0.01, ***<0.001. AOR, adjusted odds ratio; CI, confidence interval; BMI, body mass index. Models are survey-weighted logistic regressions estimating adjusted odds ratios (AOR) and 95% confidence intervals (CI) for adult heart disease. All models control for sex, race/ethnicity, urbanicity, and adult obesity. Reference groups: female, White, rural, and non-obese in adulthood. Baseline BMI: Mean BMI within each developmental period. Duration of obesity: Total number of years classified as obese within the developmental window. Excess BMI-years: Cumulative excess BMI (above the obesity threshold) across the developmental period, integrating both severity and duration of obesity.

Table 4. Association between childhood obesity dynamics and adult diabetes (age 30-40 years) across developmental periods

Outcome: Diabetes								
Predictors	Model 1		Model 2		Model 3		Model 4	
	AOR	95% CI	AOR	95% CI	AOR	95% CI	AOR	95% CI
Male	0.91	(0.63, 1.30)	0.93	(0.65, 1.34)	0.84	(0.57, 1.24)	0.85	(0.59, 1.24)
Hispanic	0.93	(0.63, 1.37)	0.91	(0.62, 1.34)	0.86	(0.57, 1.28)	0.88	(0.59, 1.30)
Black	1.83**	(1.13, 2.94)	1.65**	(1.04, 2.64)	1.61*	(1.01, 2.57)	1.55	(0.97, 2.47)
Urban	0.89	(0.66, 1.19)	0.91	(0.66, 1.26)	0.94	(0.68, 1.30)	0.94	(0.67, 1.31)
Mid-Childhood (4-9 yrs)								
Baseline BMI (mean)	1.07	(0.97, 1.18)					1.06	(0.96, 1.17)
Duration of obesity (years)	1.16	(0.99, 1.37)					1.00	(0.78, 1.29)
Excess BMI-Years	1.00	(0.97, 1.03)					0.96	(0.91, 1.00)
Early Adolescence (10-14 yrs)								
Baseline BMI (mean)			0.97	(0.90, 1.05)				
Duration years (years)			1.20*	(1.02, 1.41)			0.95	(0.78, 1.16)
Excess BMI			1.03*	(1.01, 1.06)			1.04*	(1.00, 1.08)
Late Adolescence (15-19 yrs)								
Baseline BMI (mean)					1.02	(0.90, 1.15)		
Duration years (years)					1.25**	(1.06, 1.47)	1.29***	(1.09, 1.53)
Excess BMI					1.01	(0.98, 1.04)	1.00	(0.98, 1.02)
Adult Obesity	2.25***	(1.45, 3.48)	1.99**	(1.23, 3.22)	1.55	(0.84, 2.85)	1.58	(0.96, 2.60)

Note: p-value: * <0.05, **<0.01, ***<0.001. AOR, adjusted odds ratio; CI, confidence interval; BMI, body mass index. Models are survey-weighted logistic regressions estimating adjusted odds ratios (AOR) and 95% confidence intervals (CI) for adult heart disease. All models control for sex, race/ethnicity, urbanicity, and adult obesity. Reference groups: female, White, rural, and non-obese in adulthood. Baseline BMI: Mean BMI within each developmental period. Duration of obesity: Total number of years classified as obese within the developmental window. Excess BMI-years: Cumulative excess BMI (above the obesity threshold) across the developmental period, integrating both severity and duration of obesity.