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ORIGINAL RESEARCH

Association of Body Mass Index in Youth With Adult Cardiometabolic Risk

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BACKGROUND: Whether long-term exposure to overweight or obesity from early life to adulthood has a detrimental influence on health outcomes is unknown. We aimed to investigate whether duration of overweight or obesity from youth to adulthood is associated with adult cardiometabolic risk.

METHODS AND RESULTS: A population-based cohort study was performed of 1268 youths, aged 3 to 18 years, with follow-ups at 3, 6, 9, 12, 21, 27, and 31 years. Duration of overweight or obesity over 31-year follow-up was calculated. Adulthood outcomes included type 2 diabetes mellitus, impaired fasting glucose, high insulin levels, high carotid intima-media thickness, hypertension, low high-density lipoprotein cholesterol, high low-density lipoprotein cholesterol and triglycerides, arterial pulse wave velocity, carotid artery compliance, Young elastic modulus, and stiffness index. Rates of overweight/obesity were 7.9% at baseline and 55.9% after 31 years. After adjustment for confounders, longer duration of overweight or obesity was associated with increased risk of all outcomes (relative risk ranged from 1.45–9.06 for type 2 diabetes mellitus, impaired fasting glucose, carotid intima-media thickness, hypertension, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, and triglycerides; β from 0.370–0.543 m/s for pulse wave velocity; −0.193 to −0.237 %/10 mm Hg for carotid artery compliance; 52.1–136.8 mm Hg·mm for Young elastic modulus; and 0.554–0.882 for stiffness index). When body mass index was further adjusted, these associations disappeared or were substantially reduced. Detrimental associations of adult body mass index with all outcomes were robust to adjustment for confounders and duration of overweight or obesity.

CONCLUSIONS: Overweight or obesity in adulthood rather than childhood appears to be more important for adult cardiometabolic health.

Key Words: cardiometabolic health ■ cohort ■ duration of overweight ■ pediatric

Cardiometabolic diseases represent a major health burden worldwide.[1,2] The burden continues to rise, largely because of the global epidemic of overweight and obesity, particularly in younger people.[3] In the past 4 decades, the number of children and adolescents (herein youth) who are obese increased >10-fold from 11 to 124 million worldwide,[4] predisposing them to an earlier onset and longer duration of overweight or obesity during their lifetime. Large cohort studies have shown that youth who were overweight or obese would not have increased cardiometabolic risk in adulthood if they became nonobese by adulthood.[5,6] However, the influence of long-term exposure to overweight or obesity from early life to adulthood on health outcomes is unknown. Addressing this evidence gap would provide important public health information about whether reducing the length of time exposed to overweight or obesity since early life is necessary in addition to resolving overweight or obesity by adulthood.

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CLINICAL PERSPECTIVE

What Is New?

- A longer exposure to overweight or obesity from childhood/adolescence to adulthood is associated with higher cardiometabolic risk as adults, but this association is largely explained by the degree of adiposity in adulthood.
- Overweight or obesity in adulthood rather than childhood may be more important for adult cardiometabolic health.

What Are the Clinical Implications?

- Reducing the time exposed to excess adiposity through youth to adulthood may be an effective strategy for preventing cardiometabolic diseases in adulthood primarily through reducing high adult risk of overweight or obesity.

Nonstandard Abbreviations and Acronyms

BMI	body mass index
cIMT	carotid intima-media thickness
RR	relative risk
T2DM	type 2 diabetes mellitus
YFS	Cardiovascular Risk in Young Finns Study

Two cohort studies assessed the relationship between the age at onset of overweight and obesity (childhood/adolescence, young, and mid adulthood) and adult glucose metabolism and diabetes mellitus, showing that earlier onset of overweight or obesity was associated with higher risk of impaired glucose metabolism and diabetes mellitus in adulthood, partially independent of adult adiposity.[7,8] To our knowledge, no study has examined the influence of the duration of overweight or obesity from early life to adulthood on multiple cardiometabolic risk outcomes in adulthood. Thus, this study aimed to examine whether longer duration of overweight or obesity from youth to adulthood is associated with multiple cardiometabolic outcomes in adulthood and whether this association is independent of adult adiposity.

METHODS

Data Availability Statement

The data that support the findings of this study are available from the corresponding author on reasonable request.

Study Population

In 1980, 3596 participants aged 3 to 18 years were recruited for baseline assessment of the prospective YFS (Cardiovascular Risk in Young Finns Study).[9] They were followed up 3, 6, 9, 12, 21, 27, and 31 years after baseline. The latest adult follow-ups were conducted in 2001, 2007, and 2011 (ie, 21, 27, and 31 years after baseline), when 2283 (aged 24–39 years), 2204 (aged 30–45 years), and 2060 (aged 34–50 years) of the original participants from the baseline survey in 1980 were re-examined, respectively. Participants were included if they had no missing data for body mass index (BMI) measures at baseline and the 3-, 6-, and 31-year follow-ups (ie, at least 4 observations for each participant). We also excluded participants who were pregnant at the adult follow-ups (ie, 21, 27, and 31 years) or had type 1 diabetes mellitus. Finally, 1451 participants were included for BMI imputation (see Statistical Analysis section for more information) and 1268 were included for data analyses of the current study (183 participants were excluded because they had missing data for confounders or did not have any adult outcomes described in the Adult Outcomes section below). All participants provided written informed consent, and the study was approved by local ethics committees.

Duration of Overweight or Obesity

Height and weight were measured at baseline and each follow-up and BMI was calculated as weight/height^2 (kg/m^2). Overweight or obesity at each time point was defined using the International Obesity Task Force definition.[10] Overweight or obesity status at 2 consecutive time points was used to estimate the duration of overweight or obesity for the interval between the 2 time points.[9] For example, 3 years were considered for the interval between baseline and the 3-year follow-up when a participant was overweight or obese in both survey years or 1.5 years when overweight or obese in only one of the years. The total duration for each outcome was calculated by summing all durations from baseline to the survey year when the outcome was last measured (ie, 27-year follow-up for carotid intima-media thickness [cIMT] and all stiffness outcomes, and 31-year follow-up for all other outcomes). The total duration was classified into 4 categories for data analyses (0, 0–10, 10–20, and >20 years).

Adult Outcomes

Type 2 diabetes mellitus (T2DM) was confirmed if participants had fasting plasma glucose ≥7 mmol/L (126 mg/dL), were diagnosed by a physician, had glycated hemoglobin ≥6.5% (48 mmol/mol) at the 31-year follow-up, used glucose-lowering medication

at 27- or 31-year follow-ups (including metformin, pioglitazone, glyburide, vildagliptin, and sitagliptin), or were validated by the National Social Insurance Institution Drug Reimbursement Registry. Impaired fasting glucose was defined as having a fasting plasma glucose ≥5.6 but ≤6.9 mmol/L using the latest available measurement[11]. Other adulthood outcomes were high insulin levels, hypertension, high-risk lipid levels, and high cIMT. These outcomes were defined using the latest available data from the 21-, 27-, or 31-year follow-ups as[6]: high insulin (insulin levels ≥75th sex-specific percentile); hypertension (systolic blood pressure ≥140 mm Hg or diastolic blood pressure ≥90 mm Hg or self-reported use of blood pressure–lowering medication); high low-density lipoprotein cholesterol (≥160 mg/dL [4.14 mmol/l] or taking lipid-lowering medication; low high-density lipoprotein cholesterol (<40 mg/dL [1.03 mmol/l]; high triglycerides (≥200 mg/dL [2.26 mmol/l]); and high cIMT (cIMT ≥90th percentile for age-, sex-, and study-year-specific values). Arterial stiffness was measured at 21- and/or 27-year follow-up as previously described, including arterial pulse wave velocity, carotid artery compliance, Young elastic modulus, and stiffness index.[12,13] The latest available data were used.

Childhood Factors

Smoking habits were asked during a medical examination in a solitary room. Youth smoking for participants younger than 12 years at baseline (1980) was defined as smoking daily, using available data from the subsequent follow-ups if they were aged 12 to 18 years at the time of survey. For those aged 12 to 18 years at baseline, youth smoking was defined as regular cigarette smoking on a weekly basis (or more often). The frequency of food consumption, including fruits and vegetables, was assessed by a questionnaire asking habitual dietary choices during the past month (1=daily or more often, 2=almost daily, 3=a couple of times per week, 4=once a week, 5=a couple of times per month, and 6=more seldom or not at all). Questionnaires were also used to collect data on physical activity, and an age-standardized physical activity index was calculated,[14] which has been shown to be reliable and valid.[15] Briefly, the questionnaires asked about exercise/physical activity habits, including intensity and frequency of exercise, athletic club attendance (frequency of participating in training at an athletic club), athletic competitions (whether participated in club-, district-, or national-level competitions), leisure time (usual activities during spare time: indoors, mostly indoors, and mostly outdoors), and sports participation. We used a parent-completed questionnaire for participants aged 3 and 6 years and self-reported questionnaire for those aged 9 to 18 years. Questionnaires were also used to obtain information on parental history of T2DM, BMI, and years of education (as a measure of socioeconomic status).

Adulthood Factors

Information on adult education, physical activity, and smoking was obtained with questionnaires at 21-, 27-, and 31-year follow-ups and the latest available data were used. Physical activity index was calculated by summing up different variables concerning exercise habits, including intensity, frequency, time spent exercising, and supervised exercise. A high value indicates that the participant was more active (ranging from 5–15). Participants were asked to report how often they smoke (0=never or less than daily; 1=daily). In 2011, diet was assessed by a validated 128-item food frequency questionnaire with details described elsewhere.[16,17] Briefly, participants were asked to report their usual eating habits during the past 12 months with questions classified into 12 subgroups (eg, dairy products, vegetables, and fruits and berries).

Statistical Analysis

Mean (SD) and number (percentage) were used, as appropriate, to describe participants' characteristics according to duration of overweight or obesity categories. The mean (95% CI) values of BMI from baseline to 31 years were plotted by the categories of the duration of overweight or obesity. Univariable (model 1) and multivariable Poisson regressions (categorical outcomes) or linear regressions (continuous outcomes) were used to estimate the associations of duration of overweight or obesity and adult BMI with outcomes. We first adjusted for age, sex, parental history of diabetes mellitus, consumption of fruit and vegetables, physical activity, smoking, and socioeconomic status (parental years of education) (model 2). To test whether the associations of duration of overweight or obesity were independent of adult degree of adiposity and vice versa, adult BMI was further adjusted when duration of overweight or obesity was the exposure of interest, and vice versa (model 3). *P* for trend for duration of overweight or obesity was estimated by considering the categories of the duration as a continuous variable. There were no significant interactions of sex and/or baseline age with duration of overweight or obesity; therefore, analyses were not stratified. We had missing data on BMI for 23% of the observations (all between the 9- and 27-year follow-ups), and a validated approach for longitudinal multiple imputation was used for missing BMI measures using existing observations of BMI, age, and survey years by the STATA function of mibmi.[18]

Five data sets were imputed (as default) and the averaged values were calculated to define overweight status as described above. To assess the impact of missing data, we performed complete case analyses by excluding participants who had missing data on BMI at the 21- or 27-year follow-up (n=293); moreover, we calculated the duration of overweight or obesity between the 6- and 21-year follow-up using the 2 consecutive survey years with available measurements for BMI if participants had missing data on BMI at the 9- or 12-year follow-up. For example, the duration between 6 and 12 years was calculated if BMI was not available at the 9-year follow-up. The results using imputed BMI are presented. STATA 15.1 (StataCorp LLC) was used for all analyses and a 2-tailed *P* value of 0.05 was considered statistically significant.

RESULTS

Table 1 shows baseline and adulthood characteristics of participants by duration of overweight categories. Rates of overweight were 7.9% at baseline and 55.9% after 31 years of follow-up, while the corresponding rates of obesity were 1.0% and 20.5%, respectively. Figure S1 demonstrates the mean and 95% CI of BMI from 1980 to 2011 by the categories of the duration of overweight or obesity. Compared with the other 3 categories, the category with the longest duration had the highest BMI in 1980 and this remained during the whole follow-up period. The 3 categories with duration of overweight shorter than 20 years had only slight differences in BMI in 1980 but this difference became increasingly apparent over the follow-up period. The category of 10 to 20 years had the largest increase in BMI, which was similar to the category of >20 years.

Univariable analyses showed significant dose-response associations of the duration of overweight or obesity with all adulthood outcomes (model 1; Table 2, Table S1, and Figure 1). After adjustment for confounders (model 2), these associations remained similar or were slightly reduced. However, when the analyses were further adjusted for adult BMI, the associations of duration of overweight or obesity with T2DM, impaired fasting glucose, cIMT, pulse wave velocity, carotid artery compliance, Young elastic modulus, stiffness index, and low-density lipoprotein cholesterol disappeared or were largely attenuated (model 3, Table 2 and Table S1). Longer duration of overweight or obesity was significantly associated with increased risk of having high insulin levels (compared with 0 years; relative risk [RR], 2.98 [95% CI, 1.94–4.56] for 0–10 years; 3.44 [95% CI, 2.23–5.32] for 10–20 years; and 2.94 [95% CI, 1.84–4.67] for >20 years), low high-density lipoprotein cholesterol (compared with 0 years; RR, 1.51 [95% CI, 1.03–2.19] for 0–10 years; and 1.63 [95% CI, 1.08–2.42] for 10–20 years), and high triglyceride levels (compared with 0 years; RR, 2.11 [95% CI, 1.07–4.18] for 0–10 years, 2.91 [95% CI, 1.48–5.73] for 10–20 years, and 2.14 [95% CI, 0.98–4.68] for >20 years). There was a trend for higher risk of hypertension (compared with 0 years; RR, 1.50 [95% CI, 0.99–2.29] for 0–10 years, 1.46 [95% CI, 0.94–2.26] for 10–20 years, and 1.61 [95% CI, 0.99–2.62] for >20 years; *P* for trend=0.09). Adult BMI was detrimentally associated with all outcomes, which were robust to adjustment for confounders and duration of overweight or obesity (Table 3). Complete case analyses showed similar results (data not shown).

DISCUSSION

This population-based cohort showed, for the first time, that longer duration of overweight or obesity from youth to adulthood was associated with an increased risk of poorer cardiometabolic health outcomes in adulthood, although this association was largely mediated through adult BMI. The detrimental associations of adult BMI with all cardiometabolic outcomes were robust to adjustment for confounders and duration of overweight or obesity from youth to adulthood. These findings suggest that overweight or obesity in adulthood rather than childhood appears to be more important for adult cardiometabolic health. However, reducing the time exposed to excess adiposity from youth to adulthood may be an effective strategy for reducing cardiometabolic risk associated with overweight or obesity in adulthood.

Our findings are biologically plausible. For example, a recent animal experiment showed that long-term but not short-term exposure to obesity-related change in faecal microbiota was associated with increased insulin resistance in mice.[19] Moreover, an early onset of and a longer exposure to overweight or obesity may also increase the time exposed to metabolic dysfunctions/disturbances, which, in turn, could increase cardiometabolic risk in adulthood. Nevertheless, this needs to be confirmed by clinical data examining the duration of obesity-related metabolic dysfunctions/disturbances (eg, impaired fasting glucose or insulin resistance) with hard outcomes such as stroke.

Both longer duration of overweight/obesity and high adult BMI may have an early-life origin as BMI tracks moderately from childhood to adulthood.[20] Moreover, our data showed that individuals with a longer duration of overweight or obesity had significantly higher BMI in adulthood, which was associated with all outcomes in the present study, independent of duration of overweight or obesity. This underpins the importance of preventing

Table 1. Participant Characteristics in Youth (1980) and Adulthood in the YFS

Youth	Duration of Overweight or Obesity, y				*P* Value
	0 (n=478)	0 to 10 (n=297)	10 to 20 (n=259)	>20 (n=234)	
Age, y	9.6 (4.8)	9.3 (4.9)	9.5 (4.6)	12.1 (4.8)	<0.001
Women, %	64.2	48.2	45.2	45.7	<0.001
BMI, kg/m^2	16.5 (2.3)	17.1 (2.3)	17.4 (2.4)	20.3 (3.3)	<0.001
Physical activity index (*z* score)	−0.08 (0.95)	0.003 (1.00)	0.07 (1.01)	0.14 (1.05)	0.04
Parental history of diabetes mellitus, No. (%)	7 (1.5)	8 (2.7)	8 (3.1)	5 (2.1)	0.48
Fruit intake (>6 times per wk), No. (%)	398 (83)	251 (85)	202 (78)	184 (79)	0.10
Vegetable intake (>6 times per wk), No. (%)	167 (35)	112 (38)	86 (33)	65 (28)	0.11
Smokers, No. (%)*	112 (23)	85 (29)	76 (29)	77 (33)	0.046
Maternal BMI, kg/m^2	22.7 (3.2)	23.4 (3.3)	24.4 (4.0)	25.3 (4.0)	<0.001
Paternal BMI, kg/m^2	24.7 (2.8)	25.0 (2.7)	25.7 (3.0)	26.5 (3.2)	<0.001
Parental education, y	10.6 (3.4)	10.3 (3.2)	9.9 (2.8)	9.4 (2.7)	<0.001
Adulthood†					
Age, y	40.6 (4.8)	40.3 (4.9)	40.5 (4.6)	43.1 (4.8)	<0.001
BMI, kg/m^2	22.2 (1.8)	26.1 (2.0)	29.0 (3.4)	32.2 (4.8)	<0.001
Obesity, No. (%)	0 (0)	10 (3.4)	88 (34.0)	152 (65.0)	<0.001
Systolic blood pressure, mm Hg	113.6 (12.8)	118.0 (12.7)	121.2 (13.0)	125.2 (13.2)	<0.001
Diastolic blood pressure, mm Hg	70.5 (9.7)	74.6 (9.6)	77.1 (9.6)	80.0 (10.1)	<0.001
Low-density lipoprotein cholesterol, mmol/L	3.09 (0.76)	3.25 (0.78)	3.37 (0.82)	3.37 (0.93)	<0.001
High-density lipoprotein cholesterol, mmol/L	1.45 (0.33)	1.29 (0.32)	1.22 (0.29)	1.20 (0.29)	<0.001
Triglycerides, mmol/L	1.03 (1.60)	1.28 (0.77)	1.60 (1.21)	1.70 (1.65)	<0.001
Fasting glucose, mmol/L	5.15 (0.47)	5.31 (0.47)	5.45 (0.56)	5.64 (1.30)	<0.001
Fasting insulin, μU/L	5.85 (4.71)	8.82 (5.84)	11.12 (7.51)	14.38 (13.4)	<0.001
cIMT, mm	0.63 (0.10)	0.65 (0.10)	0.68 (0.10)	0.71 (0.10)	<0.001
Pulse wave velocity, m/s	7.83 (1.3)	8.10 (1.48)	8.43 (1.56)	8.73 (1.51)	<0.001
Carotid artery compliance, %/10 mm Hg	2.08 (0.67)	1.84 (0.64)	1.81 (0.65)	1.72 (0.70)	<0.001
Young elastic modulus, mm Hg·mm	332.9 (213.5)	393.0 (241.2)	432.7 (297.0)	512.0 (455.4)	<0.001
Stiffness index	5.77 (3.17)	6.34 (3.58)	6.53 (4.24)	7.00 (5.01)	0.004
Physical activity index	9.1 (1.8)	9.1 (1.9)	9.2 (2.0)	8.6 (2.0)	0.003
Fruit intake, g/d	337 (237)	324 (262)	288 (223)	298 (237)	0.10
Vegetable intake, g/d	404 (198)	390 (194)	368 (182)	414 (215)	0.14
Education status, No. (%)					0.12
Grammar school	38 (8.0)	29 (10.0)	24 (9.4)	24 (10.5)	
College or vocational school	213 (45.0)	128 (44.3)	134 (52.3)	119 (52.2)	
University degree	222 (46.9)	132 (45.7)	98 (38.3)	85 (37.3)	
Smokers, No. (%)	73 (15.3)	31 (10.6)	46 (17.8)	39 (16.7)	0.08

Data are expressed as mean (SD) unless otherwise indicated.

BMI indicates body mass index; and YFS, Cardiovascular Risk in Young Finns Study.

Numbers for duration categories were 484, 217, 315, and 105 for pulse wave velocity, carotid artery compliance, Young elastic modulus, and stiffness index, respectively; and 520, 233, 347, and 116 for cIMT, respectively.

*For participants younger than 12 years at baseline, youth smoking was defined as smoking daily using available data from the subsequent follow-ups if participants were aged 12 to 18 years at the time of the survey.

†All variables used data from the latest available values in adulthood (from 2001, 2007, or 2011). For adult variables, the numbers of participants were 1246 for education; 1263 for smokers; 1258 for physical activity; 1267 for fasting glucose, blood pressure, high-density lipoprotein cholesterol, and triglycerides; 1216 for carotid intima-media thickness (cIMT), and 1263 for low-density lipoprotein cholesterol.

overweight at an early stage of life and monitoring overweight status from early life through adulthood to reduce long-term exposure to excess adiposity and the risk of overweight or obesity in adulthood. Of note, recent studies have demonstrated that childhood overweight was not associated with increased cardiometabolic risk in adulthood if the overweight was resolved before puberty or adulthood compared with those who were never overweight or obese.[5,6] These findings also suggest that overweight/obesity at a later stage of life may play a more

Table 2. Association Between Duration of Overweight or Obesity Beginning in Youth and Cardiometabolic Outcomes in Adulthood (N=1268)

	n/N (%)*	Duration Category, y	Model 1 RR (95% CI)	Model 2 RR (95% CI)	Model 3 RR (95% CI)
T2DM	7/409 (1.7)	0	Reference	Reference	Reference
	4/228 (1.8)	0–10	1.03 (0.30–3.47)	0.99 (0.30–3.27)	0.55 (0.17–1.83)
	13/187 (7.0)	10–20	4.06 (1.65–10.02)†	4.11 (.64–10.30)†	1.38 (0.51–3.72)
	20/166 (12.1)	>20	7.04 (3.03–16.34)†	5.55 (2.26–13.62)†	1.10 (0.35–3.47)
		P for trend	<0.001†	<0.001†	0.59
Impaired fasting glucose	68/470 (14.5)	0	Reference	Reference	Reference
	69/293 (23.6)	0–10	1.63 (1.20–2.20)†	1.45 (1.08–1.96)†	1.13 (0.82–1.55)
	72/246 (29.3)	10–20	2.02 (1.51–2.71)†	1.76 (1.31–2.37)†	1.13 (0.78–1.62)
	68/214 (37.8)	>20	2.20 (1.64–2.95)†	1.71 (1.27–2.31)†	0.87 (0.56–1.35)
		P for trend	<0.001†	<0.001†	0.57
High insulin	26/477 (5.5)	0	Reference	Reference	Reference
	72/297 (24.2)	0–10	4.45 (2.91–6.80)†	4.49 (2.93–6.87)†	2.98 (1.94–4.56)†
	102/259 (39.4)	10–20	7.23 (4.83–10.81)†	7.36 (4.90–11.05)†	3.44 (2.23–5.32)†
	116/233 (49.8)	>20	9.13 (6.15–13.56)†	9.06 (6.08–13.51)†	2.94 (1.84–4.67)†
		P for trend	<0.001†	<0.001†	<0.001†
High cIMT	40/520 (7.7)	0	Reference	Reference	Reference
	19/223 (8.2)	0–10	1.06 (0.63–1.79)	1.04 (0.62–1.75)	0.85 (0.49–1.48)
	51/347 (14.7)	10–20	1.91 (1.29–2.83)†	1.92 (1.28–2.87)†	1.29 (0.75–2.23)
	24/116 (20.7)	>20	2.69 (1.69–4.28)†	2.69 (1.67–4.33)†	1.48 (0.69–3.15)
		P for trend	<0.001†	<0.001†	0.26
Hypertension	36/477 (7.6)	0	Reference	Reference	Reference
	46/297 (15.5)	0–10	2.05 (1.36–3.10)†	2.01 (1.34–3.03)†	1.50 (0.99–2.29)‡,*
	50/259 (19.3)	10–20	2.56 (1.71–3.82)†	2.45 (1.65–3.65)†	1.46 (0.94–2.26)‡,*
	83/234 (35.5)	>20	4.70 (3.28–6.73)†	3.55 (2.44–5.14)†	1.61 (0.99–2.62)‡,*
		P for trend	<0.001†	<0.001†	0.09
High low-density lipoprotein cholesterol	52/476 (10.9)	0	Reference	Reference	Reference
	45/295 (15.3)	0–10	1.40 (0.96–2.03)‡,*	1.24 (0.86–1.80)	1.06 (0.71–1.57)
	56/259 (21.6)	10–20	1.98 (1.40–2.80)†	1.70 (1.20–2.40)†	1.28 (0.84–1.95)
	53/233 (22.8)	>20	2.08 (1.47–2.95)†	1.55 (1.09–2.20)†	1.01 (0.60–1.68)
		P for trend	<0.001†	0.003†	0.78
Low high-density lipoprotein cholesterol	40/477 (8.4)	0	Reference	Reference	Reference
	61/297 (20.5)	0–10	2.45 (1.69–3.55)†	2.03 (1.41–2.91)†	1.51 (1.03–2.19)†
	76/259 (29.3)	10–20	3.50 (2.46–4.97)†	2.79 (1.96–3.97)†	1.63 (1.08–2.42)†
	63/234 (26.9)	>20	3.21 (2.23–4.62)†	2.61 (1.80–3.79)†	1.17 (0.72–1.90)
		P for trend	<0.001†	<0.001†	0.57
High triglycerides	12/477 (2.5)	0	Reference	Reference	Reference
	27/297 (9.1)	0–10	3.61 (1.86–7.02)†	2.93 (1.51–5.66)†	2.11 (1.07–4.18)†
	44/259 (17.0)	10–20	6.75 (3.63–12.56)†	5.23 (2.81–9.73)†	2.91 (1.48–5.73)†
	42/234 (18.0)	>20	7.13 (3.82–13.30)†	5.27 (2.84–9.79)†	2.14 (0.98–4.68)‡,*
			<0.001†	<0.001†	0.06

cIMT indicates carotid intima-media thickness; and RR, relative risk.

Model 1: unadjusted.

Model 2: adjusted for age, sex, and baseline variables (parental history of diabetes mellitus, consumption of fruit and vegetables, physical activity, smoking, and socioeconomic status).

Model 3: model 2 further adjusted for body mass index when the outcome was measured (in 2011 for impaired fasting glucose and type 2 diabetes mellitus [T2DM]).

*n/N indicates the number of cases and total number of participants in each category; sample sizes are the same for all models.

†Statistical significance ($P<0.05$).

‡$P<0.1$.

Table 3. Association Between Adult BMI and Cardiometabolic Outcomes in Adulthood (N=1268)

	No.‡,*	Model 1	Model 2	Model 3
		RR (95% CI)	RR (95% CI)	RR (95% CI)
T2DM	990	1.16 (1.12 to 1.21)	1.16 (1.11 to 1.21)	1.15 (1.09 to 1.21)
Impaired fasting glucose	1223	1.07 (1.05 to 1.09)	1.06 (1.04 to 1.08)	1.07 (1.04 to 1.10)
High insulin	1266	1.14 (1.12 to 1.15)	1.14 (1.12 to 1.15)	1.10 (1.08 to 1.13)
High cIMT	1216	1.08 (1.05 to 1.11)	1.08 (1.05 to 1.11)	1.06 (1.01 to 1.11)
Hypertension	1267	1.11 (1.09 to 1.13)	1.10 (1.08 to 1.12)	1.08 (1.05 to 1.10)
High low-density lipoprotein cholesterol	1263	1.06 (1.04 to 1.08)	1.05 (1.02 to 1.07)	1.05 (1.01 to 1.08)
Low high-density lipoprotein cholesterol	1267	1.09 (1.07 to 1.10)	1.09 (1.07 to 1.11)	1.08 (1.05 to 1.11)
High triglycerides	1267	1.12 (1.09 to 1.14)	1.12 (1.08 to 1.15)	1.09 (1.05 to 1.14)
		β (95% CI)	β (95% CI)	β (95% CI)
Pulse wave velocity, m/s	968	0.076 (0.056 to 0.096)	0.047 (0.028 to 0.065)	0.035 (0.002 to 0.067)
Carotid artery compliance, %/10 mm Hg	1121	−0.039 (−0.047 to −0.030)	−0.029 (−0.037 to −0.021)	−0.039 (−0.053 to −0.024)
Young elastic modulus, mm Hg·mm	1121	16.1 (12.6 to 19.6)	12.9 (9.4 to 16.4)	15.2 (9.2 to 21.2)
Stiffness index	1121	0.131 (0.082 to 0.179)	0.104 (0.055 to 0.153)	0.151 (0.066 to 0.236)

The relative risk (RR) or β was for 1-unit (kg/m^2) increase in body mass index (BMI).
All associations were statistically significant (P<0.05).
cIMT indicates carotid intima-media thickness; and T2DM, type 2 diabetes mellitus.
Model 1: unadjusted.
Model 2: adjusted for age, sex and baseline variables (parental history of diabetes mellitus, consumption of fruit and vegetables, physical activity, smoking, and socioeconomic status).
Model 3: model 2 further adjusted for duration of overweight or obesity.
*Sample sizes are the same for all models.

important role than that in childhood for cardiometabolic health. Nevertheless, given that overweight/obese children are at substantially higher risk of becoming obese as adults than those with normal BMI and the difficulty in resolving adulthood overweight/obesity is considerable,[21] preventing overweight and obesity at an early stage of life may be vital for reducing cardiometabolic risk in adulthood.

The findings from this study are supported by previous studies in adults[22,23] but contrast with those showing that associations between the duration of obesity and cardiometabolic health outcomes (eg, T2DM) are independent of BMI measured at the end of follow-up.[24,25] This might be because these studies have generally focused on the duration of overweight or obesity starting from young or middle adulthood, whereas in our study, youth overweight was assessed. This suggests that longer exposure to overweight or obesity in adulthood may be more important to the risk of cardiometabolic diseases later in life when the influence of concurrent BMI is excluded. This is reasonable as there is evidence that overweight or obesity in youth may be less important than that in adulthood in relation to adult cardiometabolic health.[5,6] Another explanation is that the degree of adiposity may be important. Since the proportion of obesity in youth was low in the present study (<1% at baseline), future research needs to investigate whether longer duration of obesity from youth to adulthood has a stronger link with adult cardiometabolic health.

Increased insulin concentrations and insulin resistance occur much earlier than fasting glucose rises before the onset of T2DM and related complications.[26] This may explain why the association of the duration of overweight or obesity was independent of adult BMI in the current study, as it is possible that the increased insulin concentrations seen in adulthood were mostly achieved in youth or early adulthood when the duration of overweight or obesity was predominantly assessed. Similarly, the independent association with lipids outcomes may also be caused by the same reason as dyslipidemia could also occur much earlier in youth before atherosclerotic diseases, which are generally seen in older adulthood.[27] Taken together, our results suggest that a longer duration of overweight or obesity from youth to adulthood might be more important to those outcomes that occur at an earlier stage of life.

Key strengths of this study include using data from a large population-based cohort, which had a long-term follow-up from youth to early adulthood and midlife during the global epidemic of overweight and obesity of the past 4 decades. This provided a unique opportunity to examine the long-term influence of this global public health issue. This study also has limitations. First, participants were relatively young at the end of follow-up. As a result, we were unable to examine clinical cardiovascular end points. These issues could be overcome in future follow-ups of the YFS and other long-term youth-to-adult cohorts.[28] Second, BMI

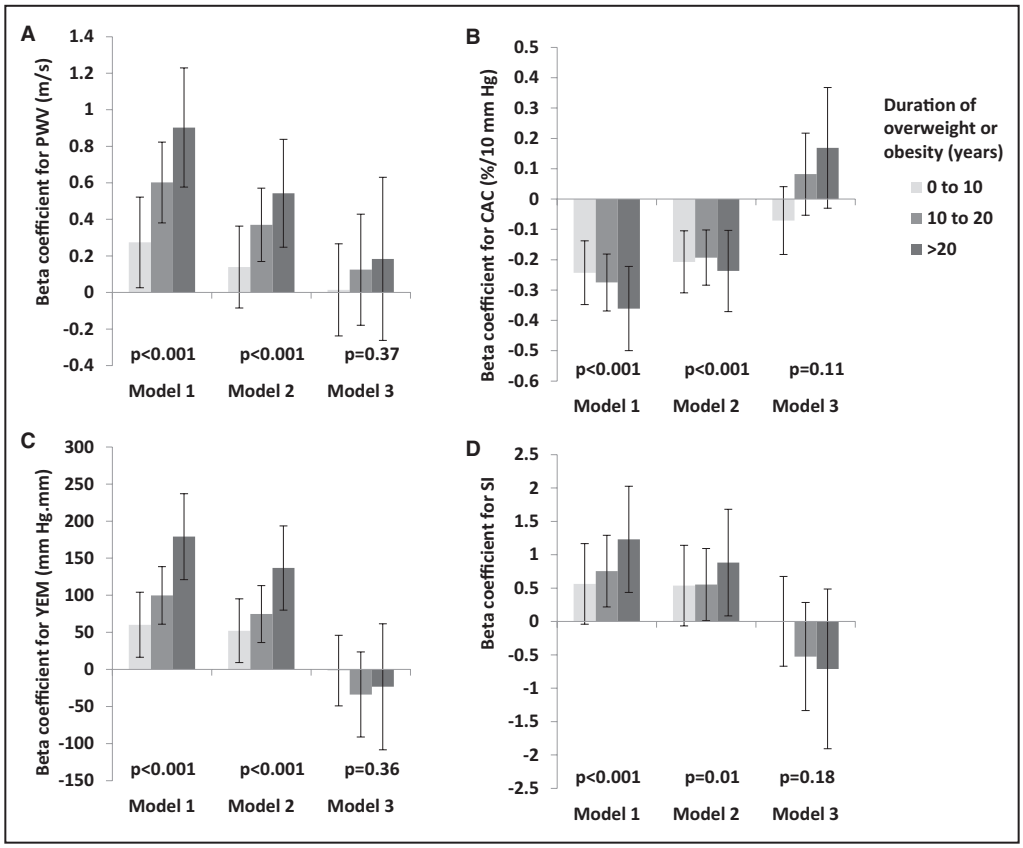

Figure. The beta coefficients and 95% CIs for associations between the duration of overweight or obesity and arterial stiffness measures during the 27-year follow-up.
A, Arterial pulse wave velocity (PWV); **B**, carotid artery compliance (CAC); **C**, Young elastic modulus (YEM); **D**, stiffness index (SI). Individuals who had no overweight or obesity (ie, the duration=0) during the 27-year follow-up were used as the reference.

was measured every 3 to 9 years (average, 4.4 years), which might have led to lower accuracy in estimating the duration of overweight. This is likely to introduce a nondifferential classification error (ie, error is the same across groups[29]), which might have underestimated the associations between duration of overweight and outcomes. However, this underestimation might be modest as BMI was measured at 3-year intervals for the first 12 years (covering the youth period for most participants) and it has been shown that BMI tracks moderately over time from youth to adulthood.[20] Nevertheless, a more frequent measurement of BMI is preferred in future studies. Third, we had missing data. However, missing BMI was imputed using a validated method for longitudinal studies[18] and results were similar to those from complete case analysis, suggesting minor impact of missing data. Moreover, the strong associations between adult BMI and all outcomes are not likely to be substantially changed, although the potential for bias cannot be completely ruled out because of missing data; thus, our conclusions remain largely unchanged. In contrast, the results of overweight or obesity duration from childhood to adulthood with adjustment for adult BMI might overestimate or underestimate the true effect since the calculation of the duration variable was, to some extent, affected by the issue of missing data. Nonetheless, the results of this study need to be interpreted with caution because of considerable missing data. Last, participants were lost to follow-up as is inherent in all longitudinal cohort studies, but the study samples were representative of the original cohorts, as previously shown.[6] Overall, future studies with more frequent measurements of BMI that start from early childhood through adulthood with hard cardiometabolic outcomes are warranted, although this would be logistically difficult and costly given the requirement for a large study sample and good retention of participants over decades of follow-up.

CONCLUSIONS

Our study suggests that a longer duration of overweight from youth to adulthood is associated with increased cardiometabolic risk in adulthood, but this association was largely mediated through adult degree of adiposity. Overweight or obesity in adulthood

rather than childhood appears to be more important for adult cardiometabolic health, but reducing the time exposed to excess adiposity from youth to adulthood may be an effective strategy for reducing cardiometabolic risk associated with overweight or obesity in adulthood.

ARTICLE INFORMATION

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Disclosures

None.

Supplementary Materials

Table S1
Figure S1

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SUPPLEMENTAL MATERIAL

Table S1. Association between duration of overweight or obesity beginning in youth and arterial stiffness outcomes in adulthood (n=1268).

	Duration category (year)	n	Model 1 β (95% CI)	Model 2 β (95% CI)	Model 3 β (95% CI)
PWV (m/s)	0	410	Reference	Reference	Reference
	0-10	192	**0.274 (0.026 to 0.522)**	0.139 (-0.085 to 0.363)	0.014 (-0.237 to 0.266)
	10-20	273	**0.602 (0.380 to 0.823)**	**0.370 (0.169 to 0.571)**	0.125 (-0.180 to 0.429)
	>20	93	**0.903 (0.578 to 1.229)**	**0.543 (0.249 to 0.838)**	0.184 (-0.262 to 0.630)
	P for trend		**<0.001**	**<0.001**	0.37
CAC (%/10 mm Hg)	0	484	Reference	Reference	Reference
	0-10	217	**-0.243 (-0.348 to -0.137)**	**-0.207 (-0.309 to -0.106)**	-0.071 (-0.183 to 0.041)
	10-20	315	**-0.275 (-0.369 to -0.182)**	**-0.193 (-0.284 to -0.103)**	0.082 (-0.053 to 0.217)
	>20	105	**-0.361 (-0.500 to -0.222)**	**-0.237 (-0.371 to -0.102)**	0.169 (-0.030 to 0.369) [a]
	P for trend		**<0.001**	**<0.001**	0.11
YEM (mm Hg·mm)	0	484	Reference	Reference	Reference
	0-10	217	**60.2 (16.3 to 104.1)**	**52.1 (9.1 to 95.1)**	-1.7 (-49.3 to 45.9)
	10-20	315	**99.8 (60.9 to 138.7)**	**74.7 (36.2 to 113.1)**	-33.8 (-91.1 to 23.6)
	>20	105	**179.1 (121.2 to 237.0)**	**136.8 (79.8 to 193.7)**	-23.4 (-108.2 to 61.5)
	P for trend		**<0.001**	**<0.001**	0.36
SI	0	484	Reference	Reference	Reference
	0-10	217	0.563 (-0.041 to 1.168) *	0.537 (-0.067 to 1.141) *	0.002 (-0.670 to 0.674)
	10-20	315	**0.755 (0.220 to 1.291)**	**0.554 (0.014 to 1.093)**	-0.525 (-1.335 to 0.285)
	>20	105	**1.231 (0.434 to 2.027)**	**0.882 (0.082 to 1.681)**	-0.711 (-1.909 to 0.486)
	P for trend		**<0.001**	**0.01**	0.18

Bold denotes statistical significance, $p < 0.05$.

*$p < 0.1$.

PWV, pulse wave velocity; CAC, carotid artery compliance; YEM, Young's elastic modulus; SI, stiffness index; CI, confidence interval.

Model 1, unadjusted.

Model 2, adjusted for age, sex and baseline variables (parental history of diabetes, consumption of fruit and vegetables, physical activity, smoking, and socioeconomic status).

Model 3, model 2 further adjusted for body mass index when the outcome was measured.

Figure S1. The mean (95% confidence intervals) values of body mass index from baseline (1980) to 31 years (2011) by the categories of the duration of overweight or obesity.