Body-mass index trajectories from childhood to mid-adulthood and their sociodemographic predictors: Evidence from the International Childhood Cardiovascular Cohort (i3C) Consortium

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Summary

Background Understanding lifecourse trajectories of body-mass index (BMI) is important for identifying groups at high risk of poor health and potential target points for intervention. This study aimed to describe BMI trajectories from childhood to mid-adulthood in four population-based cohorts established in the 1970s and 1980s and to identify childhood sociodemographic factors related to trajectory membership.

Methods Between Dec 17, 1970 and Dec 15, 1994, data were collected at the first visit from 9830 participants from the International Childhood Cardiovascular Cohort (i3C) Consortium, which includes participants from Australia (1985), Finland (1980) and the USA (1970–1994). Participants had at least three measures of height and weight, including one in childhood (6–18 years) and one in adulthood (>18 years), and were aged 30–49 years at last measurement. Latent Class Growth Mixture Modelling was used to identify lifecourse BMI trajectory groups and log multinomial regression models were fit to identify their childhood sociodemographic predictors.

Findings Five consistent BMI trajectory groups were identified amongst the four cohorts: persistently low (35.9–58.6%), improving from high (0.7–4.8%), progressing to moderate (9.3–43.7%), progressing to high (1.1–6.0%), and progressing to very high (0.7–1.3%). An additional three BMI trajectory groups were identified in some, but not all, cohorts: adult onset high (three cohorts; 1.8–20.7%), progressing to moderate-high (two cohorts; 5.2–13.8%), and relapsing yo-yoers (alternating upward and downward; one cohort; 1.3%). In pooled analyses, each predictor variable in childhood, including age, gender, parental education and race, was associated with increased likelihood of belonging to the most (e.g., improving from high) and least (e.g., progressing to very high) favourable BMI trajectory groups, suggesting a U-shaped (or inverse U-shaped) pattern of association.

eClinicalMedicine 2022;48: 101440
Published online xxx
https://doi.org/10.1016/j.eclinm.2022.101440

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Interpretation Five consistent BMI trajectory groups were identified across four cohorts from Australia, Finland, and the USA, mainly across two eras of birth. While most participants remained on a persistently low trajectory (50%), many demonstrated worsening BMI trajectories (47%), with only few demonstrating improving trajectories (<5%). Age, gender, parental education, and race appear to be important predictors of BMI trajectory group membership and need consideration in preventive and management strategies.

Funding This study was supported by funding from the National Institutes of Health, National Heart, Lung and Blood Institute (grant number R01 HL121230).

Keywords: Body mass index; Trajectory; Childhood; Adulthood; Cohort study; Predictor

Research in context

Evidence before this study

We searched PubMed using 'AND' combining the following search terms: ((body mass index[Title/Abstract]) OR (BMI[Title/Abstract]) OR (adiposity[Title/Abstract]) OR (overweight[Title/Abstract]) OR (obesity[Title/Abstract]) OR (abdominal obesity[Title/Abstract])), ((trajectory[Title/Abstract]) OR (trajectories[Title/Abstract]) OR (lifecourse [Title/Abstract]) OR (life course[Title/Abstract]) OR (life-course[Title/Abstract])), (childhood[Title/Abstract]), (adulthood[Title/Abstract]), ((predict[Title/Abstract]) OR (determine[Title/Abstract]) OR (determinant[Title/Abstract]), published from database inception to Oct 14, 2021 with no language restrictions. The search yielded 81 items with 11 potentially relevant papers undergoing full text review. Along with another two relevant papers identified by a reference list review, eight relevant papers that modelled trajectories of adiposity from childhood to adulthood and examined their childhood predictors were identified. These studies either had a limited period of follow-up ($n = 5$), excluded younger (<16 years) children ($n = 1$), examined only one independent variable ($n = 1$), or included randomised controlled trial data ($n = 1$), and none compared findings across countries.

Added value of this study

Using data from 9830 participants from four cohorts of children followed prospectively into adulthood across continents (Australia, Europe, United States) and two decades, we identified five common body mass index (BMI) trajectory groups. Most participants remained on a persistently low BMI trajectory, many demonstrated worsening BMI trajectories, and few (<5%) demonstrated improving trajectories. Individual cohort and pooled analyses showed that childhood sociodemographic factors, including age, gender, race, and highest parental education level, were important predictors of BMI trajectory group memberships.

Implications of all the available evidence

Careful consideration needs to be given to the identified sociodemographic factors in obesity prevention and management strategies. Given the rarity of the improving BMI trajectory group, strategies to prevent excess weight gain are urgently required. The public health benefits of not gaining excess weight over time and improving from a high BMI trajectory group highlight the need for further work to understand the characteristics of these groups and how some individuals appear to demonstrate 'resilience' to the current obesogenic environment.

Introduction

Overweight and obesity are amongst the most pressing public health challenges of our time. Globally, the prevalence of obesity has nearly tripled since 1975, and more than half of the world's adults were classified as overweight or obese in 2016.[1] Childhood overweight and obesity have increased more than four-fold, from 4% in 1975 to over 18% in 2016.[1] Adverse health consequences of overweight and obesity in both childhood and adulthood are well-established, making a substantial contribution to the global burden of disease. In 2015, high body-mass index (BMI) contributed to 4 million deaths globally, representing 7.1% of deaths from any cause.[2] It also contributed to 120 million disability-adjusted life-years (DALYs), representing 4.9% of DALYs from any cause.[2] The burden is anticipated to worsen, with obesity prevalence expected to reach 35% by 2025 in Australia[3] and to exceed 27% by 2030 in Finland[4] and projections suggesting an additional 65 million more adults with obesity in the United States of America (USA) and 11 million more adults with obesity in the United Kingdom (UK) by 2030. The increases in the USA and UK alone are anticipated to result in an additional 6–8.5 million diabetes cases, 5.7–7.3 million heart disease and stroke cases, 492,000–669,000 cancer cases and the loss of 26–55 million quality-adjusted life years.[5]

From a lifecourse perspective, the negative health impacts of overweight and obesity accumulate over time, with longer and sustained exposure to obesity associated with worse cardiometabolic profiles in adulthood.[6–8] Compared to adults with obesity who were

healthy weight as children, adults with obesity who were overweight or obese as children have a substantially higher risk of poorer adult cardiometabolic health outcomes, including higher carotid artery intima-media thickness, type 2 diabetes, hypertension, and high-risk high-density and low-density lipoprotein cholesterol levels.[9,10] Further, the longer an individual remains overweight or obese, the greater the economic impact.[11]

With up to 90% of children with overweight or obesity becoming adults with overweight or obesity,[12] it is essential to identify targets and opportunities where preventive and early intervention strategies may be most effective. A better understanding of BMI trajectories across the lifecourse from childhood into adulthood, and the sociodemographic factors associated with these trajectories, is useful for identifying where these leverage points may lie. While many studies have examined later health outcomes associated with varying BMI trajectories,[10,13,14] studies examining predictors of BMI trajectories have typically focused on the childhood and adolescent[15–17] or adulthood[18] periods only, and only three studies have covered the period long enough to encompass the lifecourse from childhood to mid-adulthood.[19–21] However, one of these used data from a randomised controlled trial of a nutrition supplement in a low- and middle-income country with high rates of child undernutrition,[20] one had a baseline age of 16 years (which is in the period of middle to late adolescence) and only examined one independent variable (disordered eating at 16 years),[21] and the remaining one used data from the Cardiovascular Risk in Young Finns Study [YFS] — the Finnish component of the current study.[19] To the best of our knowledge, none have compared findings across countries and continents. Only data from multiple large, established long-term cohorts that track children through adolescence and into adulthood can provide the required insights into lifecourse BMI trajectories and the sociodemographic factors that predict more and less favourable pathways. For example, a Finnish study identified six distinct BMI trajectories[10] and a Dutch study identified three distinct BMI trajectories from childhood into adulthood,[22] with most other studies describing BMI trajectories focusing solely on childhood and adolescence[23,24] or adulthood.[25] None have compared BMI trajectories or the sociodemographic predictors of these trajectories across continents. The objectives of this study were therefore: 1) to describe lifecourse BMI trajectories in four population-based cohorts established in the 1970s and 1980s across Australia, Finland and the USA; and 2) to identify the sociodemographic factors that predict lifecourse BMI trajectory group membership from childhood to adulthood.

Methods

Data sources

Data are from four cohorts of children followed prospectively into adulthood from studies in Australia (Childhood Determinants of Adult Health [CDAH] Study), Finland (YFS), and the USA (Bogalusa Heart Study [BHS], Muscatine Study [MUSC]), all members of the International Childhood Cardiovascular Cohort (i3C) Consortium.[26,27] The key aim of the i3C Consortium is to extend knowledge about the childhood origins of adult cardiometabolic diseases. Between 2015 and 2019, the i3C Consortium conducted the i3C Outcomes Study to obtain information on adult cardiovascular events and procedures and update other relevant information.[27] USA and Australian participants used a Heart Health Survey developed by the i3C investigators to collect data. The four cohorts are described here briefly.

The CDAH Study commenced across Australia in 1985 with a representative sample of 8498 children aged 7–15 years from 109 schools. In 2004–06, 3998 adults aged 26–36 years attended a study clinic or provided self-reported information via surveys, and 3038 participants completed a survey in 2009–11 at age 31–41 years. In the YFS, participants were aged 3–18 years at baseline (n = 3596) in 1980 and were followed up every 3–6 years, most recently in 2011 with 2041 participants. The BHS commenced in 1973 in the state of Louisiana, USA with nine subsequent cross-sectional examinations of children aged 3–18 years till 1994. A further 11 cross-sectional examinations were conducted at ages 19–62 years. Linkage of the 20 surveys provides 11,961 cohort members with data on at least two occasions. The most recent examination in 2013–16 included a subsample of 1298 participants. The MUSC Study is based in Iowa, USA. It commenced in 1970 with approximately 70% of the eligible school population of the city of Muscatine (a total of n = 11,377, 5–18 years at baseline) providing data in six cross-sectional examinations conducted every two years over a 12-year period. During 1982–91, a representative subset was re-examined at age 20–39 years (n = 2547), with a subsample of those participants followed longitudinally between 1992 and 2008 (n = 906). A representative subset of the childhood cohort participated in a follow-up examination in 1999–2001 (n = 594), and 82% of these participants were examined again in 2007–08.

For inclusion in the current analysis, participants were required to have at least three individual measures of BMI, including one in childhood (6–18 years) and one in adulthood (>18 years), and were aged 30–49 years at last measurement. These inclusion criteria were applied to ensure adequate representation of BMI measures over the age-window of

interest (age 6 to 50 years). Each study was granted ethical approval by the relevant ethics committee, with written informed consent obtained from participants and/or their parents throughout the timeframe of their participation.

Measures

An extensive data harmonisation process conducted during 2014–20 has resulted in a set of consistent and comparable variables across the four cohorts. BMI (kg/m^2), the key variable of interest, was derived from height and weight collected via trained technicians and/or via self-report (detailed description in Supplementary Materials 1). Potential predictor variables considered were baseline age, gender, race and highest level of parental education. All studies collected some information on race. As part of the harmonisation process, race in each study was classified into one of six categories (1=white, 2=Black/African American, 3=Native Hawaiian/Pacific Islander, 4=American Indian/Alaskan Native, 5=Asian, and 6=More than one). This variable was then collapsed into two groups (1=white, 2=Non-white) for this analysis due to a lack of variability or small cell sizes. Parental education was reported by participants in childhood in YFS, BHS and MUSC, and retrospectively reported in the first adulthood visit in CDAH study.[28] Highest level of parental education was defined as the highest of both if both parents' data were available and the only value was used if education level was available from only one parent. Given international differences in education systems, highest level of parental education was defined into four categories (less than high school, high school or equivalent, more than high school/equivalent, and university degree) and was further collapsed into two groups (more than high school/equivalent, and high school/equivalent or less) due to low proportions in some groups.

Statistical analysis

Characteristics of the four cohorts are described separately and presented as counts and proportions (%) for categorical variables and means with standard deviations (SDs) or medians with interquartile ranges (IQRs) for continuous variables, depending on normality tests by graphical and numerical methods. The former included drawing a histogram and the latter involved computing the Shapiro-Francia test.

To detect potentially biologically implausible BMI childhood values (ages 6 to ≤20 years), age-and sex-standardised BMI-z-scores (developed for this study) were generated using the STATA igrowup package that implements the WHO Child Growth Standards.[29] If the SD of generated BMI-z-scores were <-5 or >5, they were considered implausible and removed from the analysis. For adult participants (ages >18 years) who had one or more BMI values ≥60 kg/m^2, repeated BMI records were checked sequentially to establish whether the high BMI record was plausible or likely due to a recording error.

Raw BMI data were used to describe children's BMI change as a function of age, as recommended for use in longitudinal analyses.[13,30,31] Latent Class Growth Mixture Modelling (LCGMM) was used to define BMI classes (see Supplementary Materials 2).[32] To establish the ideal number of classes for each cohort separately, Bayesian information criterion (BIC) statistics, mean posterior probability, proportion of participants with posterior probability >0.7, and biological plausibility were considered.[32]

For participants with all exposure variables, sociodemographic predictors of BMI class membership were established using log multinominal regression in each cohort separately, where the 'persistently low' group was the excluded outcome category because our focus was on the higher risk BMI trajectories and BMI improving trajectory. Our rationale for this was that findings produced from this way could help to identify groups at risk of being on less healthy trajectories and who might be the focus of interventions. Relative risks (RR) and 95% confidence intervals (CI) are presented for the likelihood of being in the specific BMI trajectory group given a certain exposure variable.[33] Only variables with $P \leq 0.25$ in unadjusted analyses were added in fully-adjusted models. The detailed process of deleting, re-fitting and verifying variables has been introduced elsewhere.[34] To investigate the generalisability of findings from single-cohort predictor analyses, we conducted a one-stage individual participant meta-analysis by combining data for those participants attributed to the five BMI trajectory groups consistently identified in individual cohorts ($n = 5363$). In this pooled cohort dataset, the effect of predictors on BMI trajectory group membership was assessed using cluster-based multinomial logit models,[35] where 'cohort ID' was used as the clustering variable to adjust the standard errors.

Sensitivity analysis was conducted by using the 'progressing to moderate' BMI trajectory group as the excluded group to test the robustness of the original results. Analyses were conducted using R and Stata 15.0 (StataCorp, College Station, Texas) statistical software.

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. All authors had full access to all the data in the study and accept responsibility for the decision to submit for publication.

Results

Using BIC, mean posterior probability and proportion of participants with posterior probability >0.7

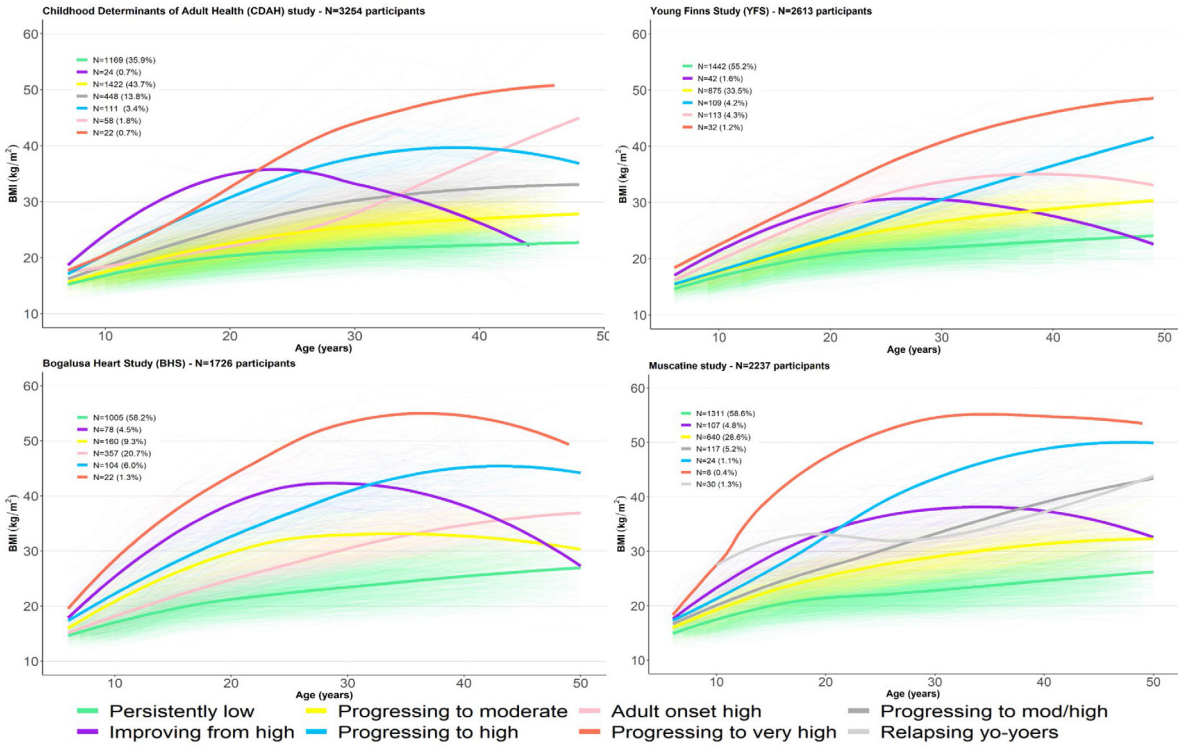

Figure 1. BMI trajectory group membership in the Childhood Determinants of Adult Health (CDAH) Study, Cardiovascular Risk in Young Finns Study (YFS), Bogalusa Heart Study (BHS) and Muscatine Study (MUSC) cohorts.

This figure shows the distinct BMI trajectories from childhood to mid-adulthood identified using the approach of Latent Class Growth Mixture Modelling, with five BMI trajectory groups consistently identified in each of the four cohorts. BMI=body-mass index.

(Supplementary Material 3), five BMI trajectory groups were consistently identified in each of the four cohorts (Figure 1). These were qualitatively labelled as 'persistently low' (35.9–58.6%), 'improving from high' (0.7–4.8%), 'progressing to moderate' (9.3–43.7%), 'progressing to high' (1.1–6.0%) and 'progressing to very high' (0.7–1.3%). An 'adult onset high' trajectory was identified in three cohorts (1.8–20.7%), a 'progressing to moderate/high' trajectory was identified in two cohorts (5.2–13.8%), and a 'relapsing yo-yoers' trajectory was identified in one cohort (1.3%).

Summary data from 7341 participants who met inclusion criteria (i.e., i. ≥ 1 measure in childhood [6–18 years], ii. ≥ 1 measure in adulthood [>18 years], and iii. a third BMI measure or the latest BMI measure taken between ages ≥ 30 and <50 years) and had data for each exposure variable are presented in Table 1, stratified by cohort. The year of birth ranged from 1952 to 1985, with the vast majority of participants (92.2%) born in the 1960s and 1970s. The kernel density distribution of year of birth is presented in Supplementary Material 4. Just less than half of all participants were men, and most were white. The prevalence of a parental education level of more than high school ranged from 36.1 to 61.1%. Median baseline age ranged from 8.0 to 11.1 years, while median age at last visit ranged from 40.0 to 46.0 years. Median BMI values at the first visit ranged from 16.4 to 17.7 kg/m^2, and at the last visit from 25.5 to 28.7 kg/m^2.

The descriptive characteristics of participants across BMI trajectory groups by cohort are presented in the Supplementary Materials 5.

Although findings were not entirely consistent across individual cohorts, multivariable models (Table 2) suggested some common predictors of BMI trajectory groups. Being 1 year older at baseline was associated with a 14–17% lower likelihood of belonging to the improving from high trajectory group, 3–6% lower likelihood of belonging to the progressing to moderate trajectory group, a 10% lower likelihood of belonging to the progressing to very high trajectory group, and a 37% higher likelihood of belonging to the relapsing yo-yoers trajectory group. This latter group was only identified in the MUSC cohort. Compared to male participants, female participants were 89% more likely to belong to the improving from high, the progressing to high (59–73% more likely), progressing to very high (383% more likely), and adult onset high (280% more likely) trajectory groups, and less likely to belong to the progressing to moderate (33–44% less likely) or progressing to moderate/high (28% less likely) trajectory groups. In the biracial cohort (BHS), those who were

Characteristics	CDAH	YFS	BHS	MUSC
Sample size	1921	2463	1726	1231
Sampling source	Schools	Random	Schools	Schools
First visit year	1985	1980	1973	1970
No of visits, range	3–4	3–8	3–15	3–10
Year of birth, range	1969–1978	1962–1977	1956–1985	1952–1971
Year of birth,% (n)				
1950–1959	0.0 (0)	0.0 (0)	5.6 (96)	30.3 (373)
1960–1969	4.1 (79)	48.8 (1201)	57.4 (991)	58.3 (718)
1970–1979	95.9 (1842)	51.2 (1262)	31.2 (539)	11.4 (140)
1980 or later	0.0 (0)	0.0 (0)	5.8 (100)	0.0 (0)
Gender,% (n)				
Male	46.7 (897)	45.6 (1124)	43.3 (747)	46.0 (566)
Female	53.3 (1024)	54.4 (1339)	56.7 (979)	54.0 (665)
Race,% (n[a])				
White	96.3 (1442)	100.0 (2463)	62.2 (1074)	99.1 (561)
Non-white[b]	3.7 (55)	0.0 (0)	37.8 (652)	0.9 (5)
Highest parental education,% (n[c])				
More than high school/equivalent	61.1 (1173)	36.1 (889)	49.1 (744)	41.6 (512)
High school/equivalent or less	38.9 (748)	63.9 (1574)	50.9 (771)	58.4 (719)
Baseline age, years, Median (IQR)	11.0 (9.0, 13.0)	9.0 (6.0, 15.0)	8.0 (6.0, 11.0)	8.0 (6.0, 12.0)
Age at last visit, years, Median (IQR)	41.0 (38.9, 44.0)	40.0 (36.0, 45.0)	42.0 (37.0, 46.0)	46.0 (41.0, 49.0)
Baseline BMI, kg/m^2, Median (IQR)	17.7 (16.1, 19.7)	17.1 (15.4, 19.7)	16.4 (15.1, 18.6)	17.2 (15.6, 19.8)
Baseline BMI-z-score, Median (IQR)	0.2 (-0.4, 0.7)	-0.1 (-0.6, 0.6)	0.1 (-0.5, 0.9)	0.4 (-0.3, 1.1)
BMI at last visit, kg/m^2, Median (IQR)	25.7 (23.1, 29.3)	25.5 (22.9, 28.8)	28.7 (24.9, 34.1)	28.2 (24.1, 32.1)
BMI trajectories				
Persistently low	36.7 (705)	55.1 (1357)	58.2 (1005)	57.8 (711)
Improving from high	0.6 (11)	1.7 (41)	4.5 (78)	5.4 (66)
Progressing to moderate	43.7 (839)	33.5 (825)	9.3 (160)	29.1 (358)
Progressing to high	3.5 (68)	4.1 (102)	6.0 (104)	1.1 (14)
Progressing to very high	0.7 (13)	1.2 (30)	1.3 (22)	0.2 (2)
Adult onset high	1.7 (32)	4.4 (108)	20.7 (357)	NA
Progressing to moderate-high	13.2 (253)	NA	NA	5.1 (63)
Relapsing yo-yoers	NA	NA	NA	1.4 (17)

***Table 1*: Summary characteristics of participants, by cohort.**
Abbreviations: BHS: Bogalusa Heart Study; BMI: body-mass index; CDAH: Childhood Determinants of Adult Health; IQR: interquartile range; MUSC: Muscatine Study; NA: not applicable; YFS: Cardiovascular Risk in Young Finns Study.
[a] *n*=1497 for CDAH and 566 for MUSC.
[b] Non-white includes Black/African American, Native Hawaiian/Pacific Islander, American Indian/Alaskan Native, Asian, and More than one.
[c] *n*=1515 for BHS.

black were more likely to belong to the progressing to high (71%), progressing to very high (321%) or adult onset high (32%) trajectory groups than those who were white. Those with lower levels of parental education (high school/equivalent or less) were more likely to belong to the improving from high (148%), progressing to moderate (31%), progressing to high (75%) and progressing to moderate/high (107%) trajectory groups than those with higher levels of parental education (more than high school/equivalent), effects mostly observed in the MUSC cohort.

In pooled analysis of the five common trajectories (n = 5363), U-shaped or inverted U-shaped associations were observed for each predictor variable (Table 2). For age, those who were one year older at baseline were less likely to belong to the more favourable (improving from high, 19% less likely) and less favourable (progressing to very high, 13% less likely) trajectory groups. Although some CIs included 1.0, female participants were more likely to belong to the more favourable (improving from high, 63% more likely) and less favourable (progressing to high, 54% more likely, and progressing to very high, 87% more likely) trajectory groups than male participants. Similarly for race, Non-white (mostly Black) participants were more likely to belong to more favourable (improving from high, 115% more likely) and less favourable (progressing to high, 119% more likely, and progressing to very high, 151% more likely) trajectory groups than white

BMI trajectories	n	Baseline age, years	Female[b]	Non-white[c]	Highest parental education, High school/equivalent or less[d]
		RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)
CDAH (*N* = 1921)					
Persistently low	705	NIIM	Excluded Class	NA	Excluded Class
Improving from high	11	NIIM	0.72 (0.22, 2.35)	NA	1.90 (0.58, 6.19)
Progressing to moderate	839	NIIM	**0.56 (0.50, 0.62)**	NA	1.07 (0.97, 1.17)
Progressing to mod/high	253	NIIM	**0.72 (0.57, 0.90)**	NA	1.18 (0.93, 1.48)
Progressing to high	68	NIIM	1.59 (0.97, 2.58)	NA	**1.75 (1.10, 2.78)**
Adult onset high	32	NIIM	**3.80 (1.57, 9.20)**	NA	0.92 (0.45, 1.86)
Progressing to very high	13	NIIM	1.00 (0.34, 2.96)	NA	2.51 (0.82, 7.64)
YFS (*N* = 2463)					
Persistently low	1357	Excluded Class	Excluded Class	NA	Excluded Class
Improving from high	41	**0.83 (0.75, 0.91)**	0.97 (0.53, 1.78)	NA	1.54 (0.80, 2.97)
Progressing to moderate	825	1.00 (0.99, 1.01)	**0.59 (0.52, 0.66)**	NA	1.03 (0.92, 1.16)
Progressing to high	102	1.00 (0.96, 1.05)	1.31 (0.89, 1.93)	NA	1.36 (0.89, 2.08)
Adult onset high	108	0.96 (0.92, 1.00)	0.81 (0.56, 1.18)	NA	1.49 (0.98, 2.25)
Progressing to very high	30	**0.90 (0.82, 0.99)**	1.46 (0.70, 3.05)	NA	2.15 (0.92, 5.02)
BHS (*N* = 1726)					
Persistently low	1005	Excluded Class	Excluded Class	Excluded Class	NIIM
Improving from high	78	**0.86 (0.78, 0.95)**	**1.89 (1.16, 3.06)**	1.22 (0.79, 1.88)	NIIM
Progressing to moderate	160	**0.94 (0.89, 1.00)**	1.12 (0.83, 1.51)	0.84 (0.62, 1.15)	NIIM
Adult onset high	357	1.00 (0.97, 1.04)	0.89 (0.74, 1.07)	**1.32 (1.10, 1.59)**	NIIM
Progressing to high	104	0.95 (0.89, 1.02)	**1.73 (1.15, 2.59)**	**1.71 (1.18, 2.47)**	NIIM
Progressing to very high	22	0.81 (0.65, 1.01)	**4.83 (1.44, 16.17)**	**4.21 (1.66, 10.67)**	NIIM
MUSC (*N* = 1231)					
Persistently low	711	Excluded Class	Excluded Class	NA	Excluded Class
Improving from high	66	**0.83 (0.76, 0.90)**	1.37 (0.86, 2.20)	NA	**2.48 (1.44, 4.25)**
Progressing to moderate	358	**0.97 (0.94, 0.99)**	**0.67 (0.56, 0.80)**	NA	**1.31 (1.09, 1.57)**
Progressing to mod/high	63	0.94 (0.88, 1.01)	1.06 (0.66, 1.72)	NA	**2.07 (1.20, 3.59)**
Progressing to high	14	1.07 (0.93, 1.22)	3.16 (0.88, 11.28)	NA	0.35 (0.12, 1.04)
Progressing to very high	2	0.57 (0.15, 2.10)	NRV	NA	1.15 (0.07, 18.38)
Relapsing yo-yoers	17	**1.37 (1.19, 1.59)**	1.04 (0.41, 2.66)	NA	1.18 (0.42, 3.29)
Pooled (*N* = 5363)					
Persistently low	3094	Excluded Class	Excluded Class	Excluded Class	Excluded Class
Improving from high	141	**0.81 (0.75, 0.88)**	1.63 (0.99, 2.70)	**2.15 (1.01, 4.58)**	**1.64 (1.41, 1.91)**
Progressing to moderate	1811	1.02 (0.97, 1.07)	**0.58 (0.52, 0.64)**	**0.44 (0.38, 0.50)**	1.01 (0.85, 1.19)
Progressing to high	256	0.97 (0.93, 1.02)	**1.54 (1.24, 1.92)**	**2.19 (1.59, 3.02)**	1.24 (0.83, 1.86)
Progressing to very high	61	**0.87 (0.81, 0.94)**	1.87 (0.98, 3.59)	**2.51 (1.84, 3.44)**	**1.78 (1.25, 2.53)**

***Table 2*: Multivariable associations (log multinomial regression) between sociodemographic factors in childhood and BMI trajectory groups from childhood to adulthood, by cohort.**[a]

Bold denotes confidence intervals that do not include 1.0.

Abbreviations: BHS: Bogalusa Heart Study; CDAH, Childhood Determinants of Adult Health; MUSC: Muscatine Study; CI, confidence interval; NA, not applicable because of either missing data or no/too few participants in some groups; NIIM, not included in model; NRV, no returned value (infinite 95% confidence interval); RR, relative risk; YFS: Cardiovascular Risk in Young Finns Study.

[a] Only variables with $P \leq 0.25$ in unadjusted analyses were added in fully-adjusted models.

[b] Compared to male.

[c] Compared to white. Non-white includes Black/African American, Native Hawaiian/Pacific Islander, American Indian/Alaskan Native, Asian, and More than one. In BHS, non-white only includes black.

[d] Compared to > High school/equivalent.

participants. Likewise, those with lower level of parental education (less than high school/equivalent) were more likely to belong to more favourable (improving from high, 64% more likely) and less favourable (progressing to very high, 78% more likely) trajectory groups than those with higher levels of highest parental education (more than high school/equivalent).

Results obtained from sensitivity analysis by using the progressing to moderate BMI trajectory as the excluded group were overall similar to the original results, with

baseline age, gender, highest level of parental education and race all predictors of BMI trajectory group membership from childhood to adulthood (Supplementary Materials 6).

Discussion

This unique international study identified five BMI trajectories that were common across countries, eras, and cohorts. While many participants remained on relatively low-risk BMI trajectory (e.g., persistently low; 35.9−58.6%), a large proportion were classified as having riskier BMI trajectories (e.g., progressing to high/very high, adult onset high; 36.6−63.4%), and very few demonstrated improving (ie, improving from high; 0.7−4.8%) trajectories. The extremely small proportion of participants in the four cohorts with improving BMI trajectories is alarming, given the current prevalence of childhood overweight and obesity[1] and future projections[5] of overweight and obesity prevalence. This key finding and other evidence noting that nearly 40% of adults with Class II/III obesity were normal weight in childhood[36] highlights the urgent and critical need to identify effective preventive strategies that limit excess weight gain even for those on low risk trajectories, and particularly during childhood and adolescence. It also emphasises the need for the development of effective weight reduction strategies for those already on less favourable BMI trajectories.

In earlier examinations of data from these cohorts, similar discordant groups of individuals—those on essentially improving BMI trajectories—demonstrated cardiometabolic profiles similar to those on more favourable BMI trajectories.[9,10] Understanding the characteristics of this particular group is important as it may point to forms of resilience to the obesogenic environment. In this study, only a very small proportion of participants were classified as belonging to an improving BMI trajectory group, ranging from 0.7% in the CDAH cohort to 4.8% in the MUSC cohort. While a plausible explanation for this deviation from the common pathway is major changes in dietary and/or physical activity behaviours resulting in a healthier weight, it is also possible that these participants had suffered from ill health or disease, have or had substance abuse issues, or had undergone bariatric surgery. Lack of uniform data collected about these variables across the cohorts prohibits examination of these potential explanatory factors. However, future work in these and other cohorts should examine these factors, and further exploration through qualitative work that may highlight greater intricacies or reveal other explanations is warranted.

While findings were not entirely uniform across individual cohorts, there were some factors that appeared to have a role in determining membership in higher risk BMI trajectory groups, specifically older age at baseline, female gender, lower level of parental education, and, in the biracial BHS cohort, being Black. These findings are supported by an earlier analysis of these datasets focused on predicting Class II/II obesity.[36]

Older age at baseline was associated with a lower likelihood of belonging to the more favourable improving from high BMI trajectory group in three (YFS, BHS, MUSC) of the four cohorts and in the pooled analysis, but also the least favourable (progressing to very high) trajectory groups. Plausibly, older children's BMI values may have stabilised and be more likely to reflect adult BMI, while younger children's BMI values may be more likely to fluctuate as they transit through adolescence.

Female participants were typically less likely than male participants to be on more favourable BMI trajectories (e.g., improving from high) and more likely to be on less favourable BMI trajectories (e.g., progressing to high, progressing to very high, adult onset high). This is consistent with evidence from the 2007−2016 National Health and Nutrition Examination Surveys in the USA, where a greater prevalence of obesity (BMI≥30 kg/m^2) and severe obesity (BMI>40 kg/m^2) was observed amongst adult women than men.[37] These findings suggest that these factors must be considered in preventive strategies, and for clinicians to closely monitor those at higher risk.

In the only biracial cohort (BHS), being Black was associated with an increased risk of being on less favourable BMI trajectories (i.e., progressing to high, progressing to very high, adult onset high). In pooled analyses, this finding was reinforced but non-white (mostly Black) participants were also more likely to belong to the more favourable improving from high trajectory group. This is consistent with findings from a number of other studies spanning adulthood including Clarke et al.,[25] who observed a social patterning of BMI trajectories over time from age 18 to 45 years whereby weight gain amongst people of racial/ethnic minorities was more rapid than amongst white individuals, and Blatrus et al.,[38] who found that Black women gained more weight over a 34-year period than white women.

Lower baseline socioeconomic position in childhood (indicated by parental education) was associated with a greater likelihood of belonging to the more (improving from high) and less (progressing to moderate, progressing to moderate/high, and progressing to high) favourable BMI trajectory groups, mostly in the MUSC study and in pooled analysis (improving from high and progressing to very high). This finding may be surprising, as evidence from developed countries on socioeconomic position and obesity suggests that lower socioeconomic position (indicated by occupation and to a less extent education) is associated with a greater likelihood of weight gain amongst adults, although only amongst white individuals.[39] However, children from higher socioeconomic groups are less likely to be obese and hence have less chance to improve their BMI from

childhood into adulthood, which is a likely explanation for this finding. Interestingly, we only observed evidence of an association between education and BMI trajectory group in the white cohorts, with no evidence in the biracial sample (BHS) where education was not retained in the final model.

Potential limitations of this study include the mixed measures of self-reported and technician-assessed height and weight, although all were technician-measured in the YFS and MUSC cohort where very similar BMI trajectory groups to the other three cohorts were identified. Other potential limitations include the small sample sizes in some analyses, and the limited number of harmonised predictor variables available for examination. Other attitudinal (e.g., self-efficacy, motivation, skills), behavioural (e.g., diet, physical activity, smoking, alcohol consumption), social (e.g., social support, peers), and contextual (e.g., economic, policy) factors could not be assessed but might contribute to BMI trajectories. Because BMI trajectories were grouped for pooled analyses after they were defined in individual cohorts, the intercepts and slopes within each cohort are not necessarily the same; however, results were mostly consistent with patterns observed in analysis of individual cohorts. Further, it was inappropriate to pool data before trajectory group generation due to heterogeneity in the cohorts including baseline and follow-up age, number of follow-ups, length between follow-ups, and average BMI values. In addition, there might be misclassification of lifecourse BMI trajectories, resulting in biased estimates of predicting associations. Although the original childhood samples were generally representative of their target population, generalisability may be an issue for the interpretation of our results, whereby data were available from 14.4 to 72.7% of the original childhood sample for trajectory modelling and from 10.8 to 68.5% of the original childhood sample for prediction analyses. Women, those with higher socioeconomic position, those married or living as married, and those with healthy weight status or lifestyles tend to be over-represented in our sample,[9,34,40–43] although there is still substantial heterogeneity in the characteristics of participants. Therefore, participants on less favourable trajectories (i.e., progressing to high or very high and adult-onset high trajectories) might have been under-represented. In addition, we caution against generalising the results to other races or ethnic groups since the study participants were predominantly white. The vast majority of our participants (92%) were born in the 1960s and 1970s, and as such, may not be applicable to today's children and young people who may follow different growth trajectories, and which may be influenced by different factors. Strengths include the availability of unique harmonised datasets from across the world spanning childhood to mid-adulthood and the use of LCGMM to model BMI trajectories, which unlike group-based trajectory modelling, takes random effects into account.

In conclusion, this study identified five common trajectories of BMI from childhood into mid-adulthood across four cohorts from three different countries mainly across two eras of birth. While the largest proportion of participants remained in the persistently low BMI trajectory group (50%), many (47%) demonstrated a worsening BMI trajectory over the lifecourse, with very few (3%) showing an improving trajectory. Age, gender, race, and parental education were all identified as sociodemographic predictors of BMI trajectory group membership. Careful consideration needs to be given to these factors in preventive strategies and clinical management. Given the rarity of the improving BMI trajectory group, strategies to prevent excess weight gain are urgently required. The public health benefits of not gaining excess weight over time and improving from a high BMI trajectory group highlight the need for further work to understand the characteristics of these groups and how some individuals appear to demonstrate 'resilience' to the current obesogenic environment.

Contributors

VC conceptualised and designed the study, contributed to the interpretation of data, drafted the initial manuscript, and revised the manuscript for important intellectual content. JT designed the study and analysis, carried out the analyses, performed the literature search and data extraction, contributed to drafting the initial manuscript, reviewed and revised the manuscript for important intellectual content. MJB designed and carried out some of the analyses, contributed to drafting the initial manuscript, reviewed and revised the manuscript. JT and MJB have verified the underlying data. CGM conceptualized and designed the study, contributed to the interpretation of data, reviewed and revised the manuscript for important intellectual content. LB, TLB, SD, TD, NHK, JI, DJ, MJ, RP, OR, AS, JS, EMU and JW contributed to the interpretation of data and reviewed and revised the manuscript. AV conceptualised and designed the study, contributed to the interpretation of the data, and critically revised the manuscript for important intellectual content. All authors had full access to all the data in the study and accept responsibility to submit for publication.

Funding

This study was supported by funding from the National Institutes of Health, National Heart, Lung and Blood Institute (grant number R01 HL121230).

Data sharing

Any reasonable requests to share data will be considered by the International Childhood Cardiovascular Cohort Consortium steering committee subject to institutional agreements and ethics approvals. Information retrieved

through literature review can be shared by contacting the first author at J.Tian@utas.edu.au.

Declaration of interests

We declare no competing interests.

Acknowledgments

The CDAH study was supported by the Commonwealth Department of Sport, Recreation and Tourism, the Commonwealth Department of Health, the Commonwealth Schools Commission, the National Heart Foundation, the National Health and Medical Research Council (grant numbers 211316, 544923, 1128373), the Tasmanian Community Fund, Veolia Environmental Services, and the Mostyn Family Foundation. The Bogalusa Heart Study has been financially supported by National Heart, Lung and Blood Institute and National Institute on aging (grant numbers R01 AG016592, R03 AG060619). The Muscatine Study has been financially supported by SCOR-Lipids, Atherosclerosis and Thrombosis HL14230, and R01s HL20124, HL48050, HL54730, HL61857. The Young Finns Study has been financially supported by The Academy of Finland, University Hospital grants (government funding to University Hospitals), and several Finnish Foundations. VC is supported by a National Heart Foundation of Australia Future Leader Fellowship (ID 100444). JT is supported by a National Heart Foundation of Australia Postdoctoral Fellowship (ID 102614). CGM was supported by a National Heart Foundation of Australia Future Leader Fellowship (100849) and is currently supported by a National Health and Medical Research Council (NHMRC) Investigator Grant (APP1176494). The contents of the published material are solely the responsibility of the individual authors and do not reflect the views of the NHMRC. We thank the teams that collected data at all measurement time points across all study centers; the persons who participated as both children and adults in these longitudinal studies; and biostatisticians Professor Leigh Blizzard and Mr. Petr Otahal for statistical advice.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.eclinm.2022.101440.

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