ARTICLE

Factors Affecting the Stability of Blood Lipid and Lipoprotein Levels From Youth to Adulthood

Evidence From the Childhood Determinants of Adult Health Study

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Objective: To examine the effect of lifestyle changes on the stability of blood lipid and lipoprotein levels from youth to adulthood.

Design: Prospective cohort study.

Setting: Australia.

Participants: Five hundred thirty-nine young adults who underwent measurement at baseline in 1985 when aged 9, 12, or 15 years and again at follow-up between 2004 and 2006.

Main Exposures: Changes in adiposity, cardiorespiratory fitness, saturated fat intake, smoking, and socioeconomic position.

Main Outcome Measures: Child and adult blood lipid levels.

Results: Using established cut points, we found that substantial proportions of individuals with high-risk blood lipid and lipoprotein levels at baseline no longer had high-risk levels at follow-up. Of the participants who had high-risk levels in youth, those with greater increases in adiposity or who commenced or continued smoking were more likely to maintain high-risk blood lipid and lipoprotein levels ($P < .05$). Participants who became high risk at follow-up had greater increases in adiposity, were less likely to improve their socioeconomic position, and tended to become less fit between surveys compared with those who maintained normal-risk levels ($P \leq .05$). These effects tended to remain ($P \leq .10$) after adjustment for all predictive lifestyle variables.

Conclusions: Unhealthy lifestyle changes that occur between youth and adulthood affect whether an individual maintains, loses, or develops high-risk blood lipid and lipoprotein levels in adulthood. Interventions that promote weight control in the first instance, but also physical activity, not smoking, and improved socioeconomic position in the transition from youth to adulthood, are likely to be of benefit in preventing adult dyslipidemia.

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In epidemiological studies, the term *tracking* describes the degree of consistency over time of an attribute and is used to evaluate the longitudinal development of risk factors for chronic diseases.[1] From a pediatric perspective, tracking analyses are useful because they determine the ability to predict future values from measurements taken early in life and also determine what risk factors, if any, should be the target of early treatment or prevention. The indicators of tracking generally include the correlation between repeated measurements of the same attribute at 2 different times and the proportion of participants who remain within a specific group (eg, categories based on quantiles of the variable's distribution or clinically defined cut points) over time. Because of their causal relationship with cardiovascular disease in adulthood, blood lipid and lipoprotein levels have been investigated for tracking in the pediatric setting.

In the past 25 years, 10 prospective studies have reported tracking of lipid and lipoprotein levels from childhood or adolescence (hereinafter referred to as youth) into adulthood.[2-16] Although these studies found that youth levels correlate well with adult levels, they have shown that a substantial proportion of youth with high-risk levels will not have high-risk levels in adulthood and that a substantial proportion of adults with high-risk levels had normal levels as youth.[16,17] That is, there exists a reasonable amount of instability in the classification of blood lipid and lipoprotein levels in youth. As such, these findings have called into question the approach to and utility of screening for

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pediatric lipid disorders.[18-20] One possible explanation for poor tracking is that youth who do not track (ie, who have an unstable classification) may be those who adopt a healthier lifestyle or a less healthy lifestyle in the intervening period. The aim of this study was to examine the effect of lifestyle changes on the stability of blood lipid and lipoprotein levels from youth to adulthood.

METHODS

Additional information on measures and statistical analyses is provided in the supplementary Methods section (http://www.archpediatrics.com).

PARTICIPANTS

The Childhood Determinants of Adult Health Study is a population-based prospective cohort study of a representative sample of 8498 Australian school children aged 7 to 15 years first undergoing assessment in 1985.[21] Of these, 5170 completed a short follow-up questionnaire, and a subset of 2410 attended 1 of 34 follow-up field clinics held across Australia from 2004 to 2006, when the study population was aged 26 to 36 years. Fewer participants attended clinics because of the burden associated with travel and completing approximately 3 hours of tests. At baseline, youth were selected using 2-stage (school, then student) probability sampling that achieved a nationally representative sample; full details have been provided elsewhere.[22] Blood collection was restricted to those aged 9, 12, and 15 years (2809 eligible participants) owing to economic and time constraints, and 1770 provided a blood sample. Of these, 539 (30.5%) provided a second blood sample at follow-up. Written participant consent was obtained at baseline and follow-up, and the study had institutional ethics approval at both time points.

MEASURES

Fasting Blood Lipid and Lipoprotein Level Measurements

In 1985, plasma total cholesterol and triglyceride levels were determined enzymatically, and high-density lipoprotein cholesterol (HDL-C) levels were analyzed after precipitation of apoprotein B–containing lipoproteins. In 2004 to 2006, serum concentrations of total cholesterol, triglycerides, and HDL-C were determined enzymatically.[17] Low-density lipoprotein cholesterol (LDL-C) concentrations were determined using the Friedewald formula.[23]

Lifestyle-Related Measures

Height and weight were measured and body mass index was calculated. Waist circumference and skin-fold thickness were measured at both time points.[24] Participants who indicated they smoked a cigarette on 1 or more occasions per week were classified as smokers. Cardiorespiratory fitness was estimated at baseline and follow-up as physical working capacity at a heart rate of 170 beats/min on a bicycle ergometer (Monark Exercise AB, Vansbro, Sweden) according to standard protocols.[25] Participants retrospectively reported the highest level of education completed by their mother/female guardian and their father/male guardian (low indicates school only; medium, trade/vocational certificate; AND high, university). The highest level of parental education achieved was used as an indicator of youth socioeconomic position (SEP). At follow-up, self-reported highest level of education completed was used as the indicator of SEP. Participants aged 12 and 15 years at baseline recorded their food consumption during a 24-hour period.[26] At follow-up, food habits and food frequency questionnaires were completed.[27] Scores from 3 questions linked to fat intake (type of milk usually consumed, frequency of trimming fat from meat, and type of spread usually used on bread) were summed to derive a single variable of dietary behavior relating to fat intake at follow-up.[24] At follow-up, female participants were asked whether they were currently using any of the following hormonal contraceptives: combined oral contraceptives, a progesterone-only pill, a weekly contraceptive patch, progestogen, progestogen injection, a progestin-releasing intrauterine device, or a progestin-releasing implant.

STATISTICAL ANALYSES

Tracking of Blood Lipid Levels From Youth to Adulthood

Tracking was estimated in the following 2 ways: (1) Spearman rank correlation coefficients and (2) the proportion of participants who remained in high-risk categories in youth and adulthood. To classify youth levels, we used pediatric high-risk cut points[20,28] that have been shown to be the best predictors of adult dyslipidemia in data from 3 cohorts[17] (eTable 1). We used high-risk cut points stipulated by the National Cholesterol Education Program's Adult Treatment Panel to classify adult levels of total cholesterol (≥240 mg/dL), LDL-C (≥160 mg/dL), HDL-C (<40 mg/dL), and triglycerides (≥200 mg/dL) (to convert total cholesterol, LDL-C, and HDL-C to millimoles per liter, multiply by 0.0259; triglycerides to millimoles per liter, multiply by 0.0113).[29]

Factors Affecting Stability of Blood Lipid Levels From Youth to Adulthood

To determine the factors that might affect the stability of youth lipid and lipoprotein levels, participants were divided into 4 tracking groups depending on their status in youth and adulthood. Participants who remained in high-risk categories at both time points were considered true-positives, those who were in high-risk categories in youth but not at follow-up were considered false-positives, those who were not in high-risk categories in youth but were in adulthood were considered false-negatives, and those who were not in high-risk categories at either time point were considered true-negatives (eFigure). In separate analyses for each lipid or lipoprotein, logistic regression was used to examine the effect of changes in lifestyle-related variables (adiposity measures, cardiorespiratory fitness, SEP, smoking, and saturated fat intake) between youth and adulthood that increased the odds of being true-positives (stable tracking) as opposed to false-positives (unstable tracking) in those who were at high risk in youth and to identify factors that increased the odds of being false-negatives (unstable tracking) as opposed to true-negatives (stable tracking) in those who were at low risk in youth. The logistic regression models were adjusted for age and sex. If multiple lifestyle variables were found to be associated with tracking of a single lipid or lipoprotein variable, a model that included all significant lifestyle variables in addition to age and sex was fitted to test for independent effects. There were no significant sex interactions, so we did not analyze the data stratified by sex.

Changes in continuous lifestyle-related variables (adiposity measures, cardiorespiratory fitness, and saturated fat intake) were analyzed using the difference (adult minus youth) of age- and sex-specific z scores at each time point. For change in SEP, a social mobility variable was created[30] using the high-

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est level of parental education at baseline and the highest level of the participant's own education at follow-up to derive change or stability in SEP as follows: persistently low (low at baseline and follow-up), persistently medium (medium at baseline and follow-up), persistently high (high at baseline and follow-up), upwardly mobile (moving from low at baseline to medium or high at follow-up or from medium at baseline to high at follow-up), and downwardly mobile (moving from high at baseline to medium or low at follow-up or from medium at baseline to low at follow-up).

RESULTS

COMPARISON OF BASELINE CHARACTERISTICS OF PARTICIPANTS AND NONPARTICIPANTS

Participants in the study sample with baseline and follow-up blood lipid and lipoprotein levels (N=539) were more likely to be female (50.1% vs 45.4%), less likely to be smokers (10.8% vs 14.2%), and more likely to be of high SEP in youth (28.2% vs 21.0%) compared with nonparticipants (those eligible from baseline who did not attend follow-up [n=1231]). Otherwise, participants were similar to nonparticipants.

PARTICIPANT CHARACTERISTICS

Key child and adult characteristics of participants are summarized in **Table 1**. Mean (SD) length of follow-up between the 2 surveys was 20.0 (0.5) years.

TRACKING OF BLOOD LIPID AND LIPOPROTEIN LEVELS FROM YOUTH TO ADULTHOOD

Spearman rank correlation coefficients for tracking of blood lipid and lipoprotein levels from youth to adulthood are presented in **Table 2**. Overall, rank-order tracking was strongest for LDL-C levels in male and female participants, followed by total cholesterol and HDL-C levels, with triglyceride levels displaying the lowest rank-order tracking (Table 2). Tracking of blood lipid and lipoprotein levels was generally consistent for male and female participants, with the exception of triglyceride levels, for which baseline levels in male participants tended to track more strongly into adulthood than baseline levels in female participants. No clear age differences were observed in correlation coefficients, although for triglyceride levels the lowest values were seen in boys and girls aged 9 years at baseline.

Tracking within the high-risk categories was generally low for all lipid and lipoprotein levels with the exception of HDL-C levels in male participants (**Figure 1**). Male participants showed greater stability in high-risk categories compared with female participants. Among male and female participants classified as having high triglyceride levels in youth, most (77 of 97 [79%] and 98 of 101 [97%], respectively) had normal levels in adulthood. Approximately 40% to 70% of participants who had high-risk total cholesterol and LDL-C levels as adults also had high-risk levels in youth (eTable 2). Most of the male and female participants with high-risk adult HDL-C or triglyceride levels did not have high-risk levels as youth.

FACTORS AFFECTING STABILITY OF BLOOD LIPID AND LIPOPROTEIN LEVELS FROM YOUTH TO ADULTHOOD

The effects of changes in lifestyle-related variables on tracking patterns are displayed in **Tables 3**, **4**, **5**, and **6**. For LDL-C, HDL-C, and triglycerides, participants who acquired high-risk levels in adulthood (false-negatives) had significantly greater increases in body mass index, waist circumference, and sum of skin-fold thickness between surveys relative to their peers who maintained normal-risk levels (true-negatives).

Of the remaining risk factors examined, participants in the false-negative HDL-C category had significantly decreased cardiorespiratory fitness levels between surveys compared with those in the true-negative category. Higher proportions of those classified as being in the true-positive category were persistent smokers or began smoking compared with those classified as false-positives for total cholesterol and HDL-C, respectively. Participants classified as being in the false-negative category for HDL-C level were less likely to have moved upward in SEP from youth to adulthood than those classified as being in the true-negative category. Tables 3 and 6 show that female participants who had total cholesterol and triglyceride levels within the reference range at baseline but had high-risk levels at follow-up (false-negatives) were more likely to be current users of hormonal contraceptives than those who had normal levels at both time points (true-negatives). In addition, female participants with adverse total cholesterol levels at both time points (true-positives) were more likely to be current hormonal contraceptive users than those who had adverse levels in youth but not in adulthood (false-positives). Although no significant differences between tracking groups was observed for change in saturated fat intake behavior, trends were in the expected direction (Tables 3 through 6).

In multivariable models that compared total cholesterol levels in participants classified as true-positive or false-positive, change in waist circumference ($P=.05$) and persistent smoking ($P=.006$) remained significant (model $R^2=7.7\%$). For HDL-C levels, multivariable models comparing true-positive with false-positive categories showed that the differences in change in waist circumference ($P=.01$) and the proportion of participants who had begun smoking ($P=.02$) remained statistically significant (model $R^2=10.8\%$). In multivariable models for HDL-C levels that compared false-negative and true-negative categories, change in waist circumference ($P<.001$) remained significant, whereas the effects for change in cardiorespiratory fitness ($P=.10$) and upward social mobility ($P=.07$) were attenuated marginally (model $R^2=13.9\%$).

Because evidence remained in the adjusted models for the effects of waist circumference, cardiorespiratory fitness, beginning smoking, and upward social mobility, we created a score using these variables to examine the effect of the number of improved lifestyle changes on the prevalence of low HDL-C levels in adulthood (**Figure 2**). The group that did not improve any lifestyle factor between youth and adulthood had more than double the prevalence of low HDL-C levels in adulthood compared with

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Table 1. Characteristics of 539 Participants in Childhood Determinants of Adult Health Who Had Blood Lipid and Lipoprotein Level Measurements at Youth and Adulthood[a]

Characteristic	Male Participants		Female Participants	
	No.	Data	No.	Data
Youth				
Age, y	269	11.9 (2.5)	270	11.9 (2.5)
Total cholesterol level, mg/dL	269	170 (28)	270	178 (30)
LDL-C level, mg/dL	266	102 (25)	267	108 (29)
HDL-C level, mg/dL	267	55 (11)	267	57 (11)
Triglyceride level, median (IQR), mg/dL	269	58 (44-74)	270	58 (48-75)
BMI	269	18.4 (2.8)	270	18.6 (2.9)
Waist circumference, cm	269	66.7 (8.6)	270	63.7 (7.8)
Skin folds, sum of 4, mm	266	31.0 (15.3)	269	41.0 (17.6)
Fitness, W/kg	255	3.09 (0.60)	250	2.50 (0.57)
Energy intake, kcal[b]	165	2491 (824)	169	1849 (548)
Fat, %[b]	165	36.7 (6.4)	169	36.9 (6.8)
Saturated fat, %[b]	165	16.1 (3.8)	169	15.8 (3.7)
Current smokers, %	263	10.7	263	11.0
Hormonal contraceptive users, %			NA	NA
Parental education, %				
School only	102	41.8	94	36.7
Trade/vocational certificate	74	30.3	73	28.5
University	68	27.9	89	34.8
Adulthood				
Age, y	269	32.4 (2.6)	270	32.4 (2.5)
Total cholesterol level, mg/dL	269	194 (37)	270	186 (40)
LDL-C level, mg/dL	264	122 (31)	270	110 (36)
HDL-C level, mg/dL	269	50 (11)	270	59 (13)
Triglyceride level, median (IQR), mg/dL	269	97 (62-142)	270	71 (53-97)
BMI	254	26.7 (3.9)	235	25.0 (5.6)
Waist circumference, cm	254	90.5 (9.7)	236	78.5 (11.6)
Skin folds, sum of 4, mm	254	66.0 (24.7)	236	78.7 (32.1)
Fitness, W/kg	232	3.07 (0.61)	197	3.02 (0.70)
Usually drink whole milk, %	250	47.6	246	31.3
Usually use butter on bread, %	251	22.7	250	24.4
Never or rarely trim fat from meat, %	250	16.4	251	7.2
Current smokers, %	254	20.1	253	14.2
Hormonal contraceptive users, %				
Not current			179	66.3
Combined estrogen-progestin			68	25.2
Progestin only			23	8.5
Education, %				
School only	100	40.2	129	48.9
Trade/vocational certificate	83	33.3	53	20.1
University	66	26.5	82	31.1

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); HDL-C, high-density lipoprotein cholesterol; IQR, interquartile range; LDL-C, low-density lipoprotein cholesterol; NA, not available.

SI conversion factors: To convert cholesterol to millimoles per liter, multiply by 0.0259; triglycerides to millimoles per liter, multiply by 0.0113.

[a] Changing numbers are the result of missing data for some participants. Baseline measurements were made in 1985 (youth); follow-up, 2004 to 2006 (adulthood). Unless otherwise indicated, data are expressed as mean (SD). Percentages have been rounded and may not total 100.

[b] Baseline dietary variables were not measured for those aged 9 years.

the study sample mean (26.2% vs 11.9%). The prevalence of low HDL-C levels in those who had improved 2 or 3 or more lifestyle factors was less than one-quarter of the study population prevalence. The mean (SD) changes in the number of positive lifestyle changes for this score was 1.4 (0.8).

COMMENT

Previous studies have shown that, although tracking of lipid and lipoprotein levels is good, it is not entirely stable. Our data show that, despite substantial rank-order tracking, a considerable proportion of high-risk youth did not have high-risk levels in adulthood, and most of those with high-risk levels in adulthood did not have high-risk levels as youth. We have demonstrated that some of this misclassification was likely the result of participants adopting changes in lifestyle habits that a screening and intervention program would be designed to promote, such as weight control, physical activity, not smoking, and improvements in SEP. Our findings are important for 2 reasons. First, they suggest that beneficial changes in modifiable risk factors (smoking and adiposity) in the time between youth and adulthood have the potential to shift

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Table 2. Correlation Coefficients for Tracking of Blood Lipid and Lipoprotein Level Measurements From Youth to Adulthood[a]

Variable	Spearman Rank Correlation Coefficients, ρ (No. of Participants)			
	Age, in 1985, y			
	9	12	15	All
Total cholesterol level				
Male participants	0.58 (95)	0.58 (86)	0.45 (88)	0.54 (**269**)
Female participants	0.55 (95)	0.49 (85)	0.56 (90)	0.54 (**270**)
LDL-C level				
Male participants	0.59 (92)	0.65 (85)	0.50 (85)	0.58 (**262**)
Female participants	0.63 (94)	0.56 (83)	0.60 (90)	0.60 (**267**)
HDL-C level				
Male participants	0.50 (94)	0.55 (86)	0.36 (87)	0.47 (**267**)
Female participants	0.56 (95)	0.26[b] (84)	0.51 (90)	0.47 (**269**)
Triglyceride levels				
Male participants	0.33 (95)	0.44 (86)	0.48 (88)	0.41 (**269**)
Female participants	0.16[c] (95)	0.38 (85)	0.28 (90)	0.26 (**270**)

Abbreviations: HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol.
[a] Baseline measurements were made in 1985 (youth); follow-up 2004 to 2006 (adulthood). Unless otherwise indicated, $P < .01$ for all comparisons.
[b] $P < .05$.
[c] $P = .13$.

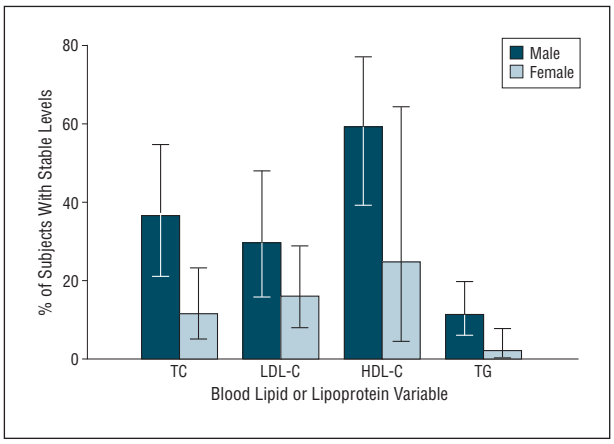

Figure 1. Proportions of male and female participants who had high-risk levels in youth and adulthood for total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), and triglycerides (TG). Error bars represent 95% confidence intervals.

those with high-risk blood lipid and lipoprotein levels in youth to low-risk levels in adulthood. Second, they emphasize that preventive programs aimed at those who do not have high-risk blood lipid and lipoprotein levels in youth are equally important if the proportion of adults with high-risk levels is to be reduced.

The effects of increased adiposity, beginning smoking, and hormonal contraceptive use in female participants on tracking of blood lipid and lipoprotein levels have been suggested in previous studies.[5-8] Associations during a longer follow-up period and with the LDL-C levels reported in this study are novel. Also new are the findings concerning change in cardiorespiratory fitness and social mobility.

Our data show that change in cardiorespiratory fitness was associated with tracking of HDL-C levels from youth to adulthood. The beneficial effect of short- to medium-term aerobic exercise training in raising HDL-C levels is well established,[31] with possible underlying mechanisms related to increased lipoprotein lipase activity in adipose tissue and muscle, reduced levels of cholesterol ester transfer protein, or decreased hepatic lipase activity.[32] The effects of exercise training on HDL-C levels are thought to be both direct and mediated through exercise-induced reductions in adiposity.[31] Although not a randomized controlled trial, our data provide observational epidemiological evidence that a long-term increase in cardiorespiratory fitness and, by association, physical activity is associated with an improved HDL-C profile. The effect was diluted with the inclusion of waist circumference in the multivariable model, but there remained weak evidence, providing support for direct and indirect effects of increased physical activity in raising HDL-C levels.

Although the Young Finns[7] and Beaver County[5,6] cohorts examined changes in indices of physical activity collected from questionnaire measurements, neither study found that physical activity significantly affected tracking of the studied blood lipid and lipoprotein variables. The discrepancy between the findings in this study with cardiorespiratory fitness and those from the Young Finns and Beaver County studies that used self-reported physical activity may be a result of reduced measurement error in the objective estimates of cardiorespiratory fitness at both time points. That is, it would seem possible that self-report physical activity data collected at 2 time points, using (in some instances) nonvalidated questions, and delivered to individuals of vastly different ages would not accurately quantify changes. Because change in cardiorespiratory fitness in an individual is strongly correlated with a change in energy expenditure and measurements are less subject to measurement error, Jackson et al[33] have argued that change in objectively measured cardiorespiratory fitness from one time point to another might be a better indicator of change in physical activity than questionnaire measures of physical activity at each time point.

For HDL-C levels, upward social mobility from youth to adulthood was associated with improvements in HDL-C

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Table 3. Factors Affecting the Tracking of Total Cholesterol Levels From Youth to Adulthood[a]

	Category							
	True-Positive		False-Positive		False-Negative		True-Negative	
Lifestyle Variable	No.	Data	No.	Data	No.	Data	No.	Data
Δ BMI, mean (SD)	19	0.26 (0.85)	158	0.07 (0.91)	55	0.31 (0.73)	257	0.11 (0.85)
Δ waist circumference, mean (SD)	19	0.43 (0.97)	159	0.01 (0.85)[b]	55	0.18 (0.77)	257	0.07 (0.93)
Δ skin folds, sum of 4, mean (SD)	19	0.23 (0.86)	159	−0.03 (1.03)	54	0.37 (0.86)	254	0.13 (1.00)
Δ cardiorespiratory fitness, mean (SD)	12	0.07 (1.47)	129	0.11 (1.14)	40	0.03 (1.12)	219	−0.05 (1.23)
Δ saturated fat intake, mean (SD)	9	−0.03 (1.52)	84	−0.06 (1.30)	48	0.19 (1.50)	166	−0.03 (1.42)
Smoking status, %								
Never smoker	10	52.6	127	79.9	39	68.4	204	78.8
Stopped smoking	1	5.3	7	4.4	5	8.8	19	7.3
Began smoking	5	26.3	22	13.8	9	15.8	28	10.8
Smoker at both time points	3	15.8	3	1.9[b]	4	7.0	8	3.1
Social mobility, %								
Persistently low	3	16.7	23	15.0	7	12.5	33	13.3
Persistently moderate	3	16.7	18	11.8	7	12.5	24	9.7
Persistently high	0	0	4	2.6	1	1.8	15	6.0
Downwardly mobile	7	38.9	57	37.3	24	42.9	88	35.5
Upwardly mobile	5	27.8	51	33.3	17	30.4	88	35.5
Female participants currently using HC, %	12	57.1	10	30.3[b]	13	52.0	56	29.3[c]

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); Δ, change in *z* score (follow-up minus baseline); HC, hormonal contraception.

[a] Percentages may not total 100 because of rounding. True-positive indicates participants are in the high-risk cluster at youth and adulthood; false-positive, in the high-risk cluster at youth but not at follow-up; false-negative, not in the high-risk cluster at youth, but were in adulthood; and true-negative, not in the high-risk cluster at youth and adulthood.

[b] $P < .05$ for comparisons between true-positive (reference group) and false-positive categories using logistic regression.

[c] $P < .05$ for comparisons between false-negative and true-negative (reference group) categories using logistic regression.

Table 4. Factors Affecting the Tracking of LDL-C Levels From Youth to Adulthood[a]

	Category							
	True-Positive		False-Positive		False-Negative		True-Negative	
Lifestyle Variable	No.	Data	No.	Data	No.	Data	No.	Data
Δ BMI, mean (SD)	18	0.39 (0.67)	127	0.02 (0.88)	56	0.47 (0.81)	279	0.08 (0.84)[b]
Δ waist circumference, mean (SD)	18	0.55 (0.83)	127	−0.03 (0.84)[c]	56	0.38 (0.92)	280	0.05 (0.89)[b]
Δ skin folds, sum of 4, mean (SD)	18	0.34 (0.74)	127	−0.03 (0.97)	55	0.49 (0.91)	277	0.11 (0.98)[b]
Δ cardiorespiratory fitness, mean (SD)	10	0.01 (1.12)	101	0.21 (1.06)	41	−0.10 (1.24)	241	−0.03 (1.25)
Δ saturated fat intake, mean (SD)[d]	7	0.03 (0.88)	65	0.00 (1.35)	45	0.20 (1.5)	185	−0.04 (1.4)
Smoking status, %								
Never smoker	10	58.8	99	76.7	42	72.4	222	79.3
Stopped smoking	2	11.8	6	4.7	4	6.9	20	7.1
Began smoking	4	23.5	20	15.5	7	12.1	31	11.1
Smoker at both time points	1	5.9	4	3.1	5	8.6	7	2.5
Social mobility, %								
Persistently low	3	16.7	16	12.8	6	11.1	40	14.9
Persistently moderate	3	16.7	11	8.8	7	13.0	30	11.2
Persistently high	0	0	3	2.4	4	7.4	13	4.9
Downwardly mobile	7	38.9	51	40.8	26	48.1	85	31.7
Upwardly mobile	5	27.8	44	35.2	11	20.3	100	37.3
Female participants currently using HC, %	12	46.2	8	30.8	12	38.7	59	32.1

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); Δ, change in *z* score (follow-up minus baseline); HC, hormonal contraception; LDL-C, low-density lipoprotein cholesterol.

[a] Percentages may not total 100 because of rounding. Categories are described in Table 3.

[b] $P < .05$ for comparisons between false-negative and true-negative (reference group) categories using logistic regression.

[c] $P < .05$ for comparisons between true-positive (reference group) and false-positive categories using logistic regression.

[d] Data available only for those aged 12 and 15 years at baseline.

risk status. This finding is consistent with a Scottish study,[34] which found that those who moved from a lower SEP in youth to a higher SEP in adulthood had higher adult HDL-C levels. The mechanisms through which improvements in SEP are related to decreases in HDL-C risk are uncertain. Plausibly, this relationship could be mediated through changes in saturated fat intake, physical activity, smoking, or adiposity, but upward social mo-

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Table 5. Factors Affecting the Tracking of HDL-C Levels From Youth to Adulthood[a]

	Category							
	True-Positive		False-Positive		False-Negative		True-Negative	
Lifestyle Variable	No.	Data	No.	Data	No.	Data	No.	Data
Δ BMI, mean (SD)	18	0.09 (1.28)	81	−0.17 (0.82)	118	0.45 (0.74)	270	0.08 (0.84)[b]
Δ waist circumference, mean (SD)	18	0.08 (1.14)	81	−0.26 (0.69)[c]	118	0.49 (0.75)	271	0.01 (0.92)[b]
Δ skin folds, sum of 4, mean (SD)	18	−0.05 (1.87)	80	−0.24 (0.89)	118	0.51 (0.81)	268	0.05 (0.97)[b]
Δ cardiorespiratory fitness, mean (SD)	13	0.06 (1.27)	66	0.19 (1.30)	95	−0.22 (1.27)	224	0.08 (1.13)[b]
Δ saturated fat intake, mean (SD)[d]	15	−0.29 (1.92)	61	0.03 (1.42)	64	0.14 (1.42)	166	−0.01 (1.33)
Smoking status, %								
Never smoker	7	41.2	68	73.9	86	79.6	215	78.8
Stopped smoking	0	0	9	9.8	8	7.4	15	5.5
Began smoking	7	41.2	10	10.9[c]	13	12.0	34	12.5
Smoker at both time points	3	17.6	5	5.4	1	0.9	9	3.3
Social mobility, %								
Persistently low	1	5.9	11	12.4	18	17.5	36	13.7
Persistently moderate	2	11.8	7	7.9	13	12.7	31	11.8
Persistently high	1	5.9	1	1.1	6	5.9	12	4.6
Downwardly mobile	10	58.8	31	34.8	43	42.2	88	33.5
Upwardly mobile	3	17.6	39	43.8	23	22.5	96	36.5[b]
Female participants currently using HC, %	6	46.2	10	25.6	3	21.4	73	36.0

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); Δ, change in *z* score (follow-up minus baseline); HC, hormonal contraception; HDL-C, high-density lipoprotein cholesterol.
[a] Percentages may not total 100 because of rounding. Categories are described in Table 3.
[b] $P < .05$ for comparisons between false-negative and true-negative (reference group) categories using logistic regression.
[c] $P < .05$ for comparisons between true-positive (reference group) and false-positive categories using logistic regression.
[d] Data available only for those aged 12 and 15 years at baseline.

Table 6. Factors Affecting the Tracking of Triglyceride Levels From Youth to Adulthood[a]

	Category							
	True-Positive		False-Positive		False-Negative		True-Negative	
Lifestyle Variable	No.	Data	No.	Data	No.	Data	No.	Data
Δ BMI, mean (SD)	12	0.32 (1.17)	188	0.07 (0.81)	37	0.53 (0.65)	252	0.10 (0.89)[b]
Δ waist circumference, mean (SD)	12	0.38 (1.28)	188	0.02 (0.84)	37	0.55 (0.67)	253	0.04 (0.91)[b]
Δ skin folds, sum of 4, mean (SD)	12	−0.15 (1.89)	187	0.09 (0.99)	36	0.56 (0.87)	251	−0.07 (0.94)[b]
Δ cardiorespiratory fitness, mean (SD)	10	−0.21 (1.10)	147	−0.02 (1.12)	32	0.25 (1.09)	211	0.02 (1.27)
Δ saturated fat intake, mean (SD)[c]	8	0.79 (1.23)	155	0.03 (1.41)	20	0.41 (1.71)	124	−0.16 (1.34)
Smoking status, %	6	54.5	134	69.4	32	76.2	208	83.9
Never smoker	0	0	23	11.9	1	2.4	8	3.2
Stopped smoking	3	27.3	24	12.4	9	21.4	28	11.3
Began smoking	2	18.2	12	6.2	0	0	4	1.6
Smoker at both time points								
Social mobility, %								
Persistently low	1	10.0	28	14.8	6	15.4	31	13.1
Persistently moderate	0	0	20	10.6	5	12.8	27	11.4
Persistently high	0	0	6	3.2	2	5.1	12	5.1
Downwardly mobile	7	70.0	80	42.3	15	38.4	74	31.2
Upwardly mobile	2	20.0	55	29.1	11	28.2	93	39.2
Female participants currently using HC, %	7	30.4	7	22.6	25	61.0	52	29.7[b]

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); Δ, change in *z* score (follow-up minus baseline); HC, hormonal contraception.
[a] Percentages may not total 100 because of rounding. Categories are described in Table 3.
[b] $P < .05$ for comparisons between false-negative and true-negative (reference group) categories using logistic regression.
[c] Data available only for those aged 12 and 15 years at baseline.

bility remained independently associated with HDL-C risk status in the multivariable model, which accounted for these and other factors. It is possible that changes in unmeasured variables such as dietary components other than saturated fat, alcohol consumption, depression, stress, or use of health services explain the observed association.

Despite trends being in the expected direction, no association between change in saturated fat intake and tracking of blood lipid or lipoprotein levels was observed. Measurement inconsistency in the diet variables used to derive

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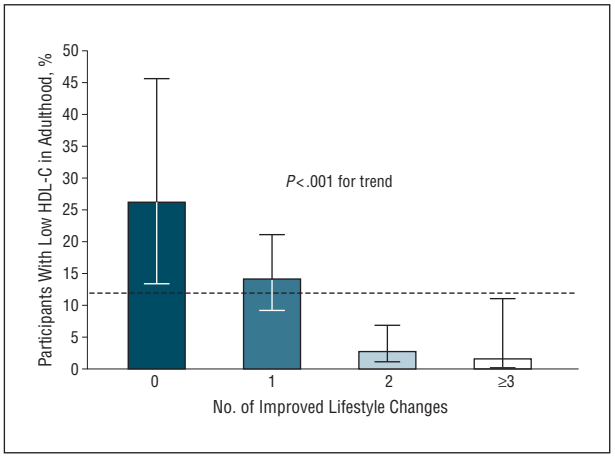

Figure 2. Proportions of participants (least squared means) with high-risk (ie, low) levels of high-density lipoprotein cholesterol (HDL-C) in adulthood according to the number of positive lifestyle changes from youth. Positive lifestyle changes included a decrease in waist circumference *z* score of 1 or more, an increase in cardiorespiratory fitness *z* score of 1 SD or more, upwardly mobile socioeconomic position (as described in the "Methods" section of the text), and not beginning or not persisting in smoking. Proportions are adjusted for age and sex. Dashed line indicates study sample mean of low HDL-C in adulthood. Error bars represent 95% confidence intervals. Numbers of participants for each group were 32 for 0 changes, 179 for 1 change, 120 for 2 changes, and 39 for 3 or more changes. *P* value for trend was calculated from the logistic model.

change in saturated fat intake in this study may have contributed to the lack of any association observed between this variable and tracking of the blood lipid and lipoprotein levels. Although related, comparing a direct assessment of saturated fat intake as a percentage of total daily caloric intake in childhood with a measure relating to saturated fat intake behavior in adulthood is, at best, only a proxy for actual changes in either variable. The data collected at both time points did not allow fat intake behavior or saturated fat intake as a percentage of total daily caloric intake to be directly assessed. The resultant measurement error from comparing these related but different indicators of saturated fat intake would likely shift any true effect toward the null.

In the absence of long-term clinical trials, analyses of the type used in this study are important because they offer insight into the likely effects of changes in modifiable risk factors on whether an individual remains at or changes risk status between youth and adulthood. The findings that health-promoting lifestyle changes in adiposity, physical activity, smoking, and socioeconomic circumstance between youth and adulthood affect tracking of blood lipid and lipoprotein levels provide direction for prevention and intervention programs to reduce cardiovascular disease risk. Although there is a paucity of evidence from clinical trials supporting prevention programs commencing in childhood or adolescence, our data go some way to supporting the recently revised American Academy of Pediatrics[19] statement for the management of hypercholesterolemia in children that endorsed population-wide preventive measures encouraging physical activity and following dietary guidelines for the reduction in dyslipidemia and for overweight or obesity.

Bias caused by loss to follow-up of almost 70% of the original eligible cohort needs to be considered. Participants at follow-up differed from nonparticipants with respect to baseline smoking and SEP. Sensitivity analyses (data not shown) suggested that baseline differences in these variables could have resulted in minor shifts in effect toward the null, meaning that the tracking estimates presented were likely a slight overestimate of the true effect.

Several potential sources of measurement error were also evident. First, single measurements of lipid and lipoprotein levels have been shown to have considerable short-term within-person variability,[35] which is offset by multiple measurements.[4,8] For our study, this suggests that the degree of tracking would likely be higher than our results suggest. Second, because data were available from only 2 time points, we had a single measure of change that did not allow the timing, duration, or frequency of changes to be examined. Third, the methods for analyzing blood samples changed between 1985 and follow-up. Although we attempted to account for this by estimating tracking from ranks and categories defined by quantiles, we are unable to determine whether some of the differences observed were the result of different analysis methods or actual changes. Fourth, youth SEP was retrospectively recalled, although this is a commonly used[34,36] and valid method that does not differ according to SEP.[37] Finally, the measure of SEP was limited to education; findings may have differed had we used an alternate indicator. However, education is stable, whereas other indicators of SEP, such as occupation or employment status, may change as people move in and out of the workforce, and income data were not collected in this study because they are typically poorly reported.

In conclusion, unhealthy lifestyle changes that occur between youth and adulthood affect whether an individual maintains, loses, or develops high-risk blood lipid and lipoprotein levels in adulthood. These data suggest that prevention and intervention programs designed to promote weight control in the first instance, but also physical activity, not smoking, and improvements in socioeconomic circumstances in the time between youth and adulthood, are important for youth with and without high-risk lipid and lipoprotein levels.

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