

# Cardiovascular Risk and the American Dream: Life Course Observations From the BHS (Bogalusa Heart Study)

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**Background**—Economic literature shows that a child’s future earnings are predictably influenced by parental income, providing an index of “socioeconomic mobility,” or the ability of a person to move towards a higher socioeconomic status from childhood to adulthood. We adapted this economic paradigm to examine cardiovascular risk mobility (CRM), or whether there is life course mobility in relative cardiovascular risk.

**Methods and Results**—Participants from the BHS (Bogalusa Heart Study) with 1 childhood and 1 adult visit from 1973 to 2016 (n=7624) were considered. We defined population-level CRM as the rank-rank slope ( $\beta$ ) from the regression of adult cardiovascular disease (CVD) risk percentile ranking onto childhood CVD risk percentile ranking ( $\beta=0$  represents complete mobility;  $\beta=1$  represents no mobility). After defining and measuring relative CRM, we assessed its correlation with absolute cardiovascular health using the American Heart Association’s Ideal Cardiovascular Health metrics. Overall, there was substantial mobility, with black participants having marginally better CRM than whites ( $\beta_{\text{black}}=0.10$  [95% confidence interval, 0.05–0.15];  $\beta_{\text{white}}=0.18$  [95% confidence interval, 0.14–0.22];  $P=0.01$ ). Having high relative CVD risk at an earlier age significantly reduced CRM ( $\beta_{\text{age}\times\text{slope}}=-0.02$ ; 95% confidence interval,  $-0.03$  to  $-0.01$ ;  $P<0.001$ ). Relative CRM was strongly correlated with life course changes in Ideal Cardiovascular Health sum ( $r=0.62$ ; 95% confidence interval, 0.60–0.65).

**Conclusions**—Results from this novel application of an economic mobility index to cardiovascular epidemiology indicated substantial CRM, supporting the paradigm that life course CVD risk is highly modifiable. High CRM implies that the children with the best relative CVD profiles may only maintain a slim advantage over their peers into adulthood. (*J Am Heart Assoc.* 2018;7:e007693. DOI: 10.1161/JAHA.117.007693.)

**Key Words:** epidemiology • pediatric • risk • risk factors/global assessment

Socioeconomic mobility, or the “American Dream,” posits that all people should have equal opportunity to improve their socioeconomic status regardless of their early-life socioeconomic circumstances. In 2014, economists Chetty and Hendren published comprehensive findings assessing the level of socioeconomic mobility nationwide and within regional “commuting zones.”<sup>1,2</sup> Using the rank-rank slope method<sup>3</sup> to plot people’s childhood versus adult income percentile rankings, they demonstrated that a child’s future income is moderately tied to parental income.

Interestingly, this method for measuring mobility is rarely used outside of economics. For policymakers looking to

understand health equality during an uncertain political transition that could drastically reshape America’s healthcare system, these methods could conceivably be extended to life course epidemiological research. This approach is already uniquely possible for measuring lifetime cardiovascular risk in several existing cohorts worldwide, such as the BHS (Bogalusa Heart Study), which contains detailed health data spanning the life course from childhood through adulthood. Herein, we adapted this economic concept to examine the potentially analogous construct of life course “mobility” in relative cardiovascular risk, which we have termed cardiovascular risk mobility (CRM). Applying this theory to our

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Accompanying Tables S1, S2 and Figure S1 are available at <http://jaha.ahajournals.org/content/7/3/e007693/DC1/embed/inline-supplementary-material-1.pdf>

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## Clinical Perspective

### What Is New?

- A methodological concept common to socioeconomic literature, but novel to epidemiology, was adapted to characterize life course mobility in cardiovascular disease risk versus one's peers.
- We found that a child ranked 10 percentiles worse in cardiovascular disease risk burden than his or her peers is likely to have only a 1 to 2 percentile disadvantage by midadulthood.

### What Are the Clinical Implications?

- Cardiovascular risk compared with one's peers is modifiable from childhood through adulthood, so establishing and maintaining healthy behaviors is important throughout the life course.
- However, we identified an age interaction that indicated that the earlier in childhood that a person's cardiovascular disease risk burden becomes worse than his or her peers, the more difficult it will be for that child to "catch up" to an equal risk stratum in adulthood.

childhood cardiovascular cohort allowed us to demonstrate the degree to which relative life course cardiovascular disease (CVD) risk is modifiable and how strongly this mobility is linked to absolute cardiovascular health.

## Methods

The data, analytic methods, and study materials will not be made available to other researchers for purposes of reproducing the results or replicating the procedure.

## Study Population

The BHS was founded in 1973 by Dr Gerald Berenson in southeastern Louisiana to investigate childhood precursors to CVD.<sup>4</sup> The BHS consists of a series of examinations during childhood, with follow-up assessments every few years through adulthood. It represents the longest continuing cardiovascular cohort in a biracial community ( $\approx 65\%$  white and  $\approx 35\%$  black) in the United States. All BHS participants with at least 1 childhood (aged  $\leq 18$  years) assessment and 1 adult (aged  $> 18$  years) visit ( $n=7624$ ) through 2016 were included in these analyses. Specific details on the collection of cardiovascular risk factors, including biomarkers, have been described previously.<sup>4,5</sup> This study used longitudinal measurements of systolic blood pressure (SBP), total serum cholesterol, fasting blood glucose, high-density lipoprotein-C (HDL-C), low-density lipoprotein-C, triglycerides, age, race, sex, height, weight, and smoking history.

## Adult and Childhood Cardiovascular Risk

Framingham 10-year risk of coronary heart disease was calculated to assess adult cardiovascular risk.<sup>6</sup> Adults were ranked by percentiles of Framingham risk (0=highest risk; 100=lowest risk). Adult CVD risk models are not validated for childhood use, so we elected to use a Z score from age and sex standardization of the risk factors included in the Framingham score to measure childhood CVD risk.<sup>7-9</sup> Each risk factor was regressed as a dependent variable onto age and sex using linear regression (total cholesterol, HDL-C, and SBP) or logistic regression (hypertension and smoking). After multiplying HDL-C residuals by  $-1$ , the residuals from each individual model were summed to form the overall continuous Z score for each child.<sup>10</sup> Children were ranked by percentiles of Z score (0=highest risk factor Z score; 100=lowest risk factor Z score).

## Absolute Cardiovascular Health

We calculated Ideal Cardiovascular Health (ICH) per criteria established by the American Heart Association (Table S1).<sup>11</sup> We limited our analyses to 5 of the 7 ICH metrics: (1) smoking, (2) body mass index (BMI), (3) blood glucose, (4) total cholesterol, and (5) SBP. For each metric, we calculated the percentage achieving the ideal criteria. We also summed the individual values (0, 1, or 2) of each metric to get an ICH sum (0 through 10) for each participant.

This study was approved by the Tulane Institutional Review Board. All participants gave informed written consent. B.D.P. analyzed the data.

## Statistical Analysis

For all included BHS participants ( $n=7624$ ), Markov Chain Monte Carlo single imputation for missing values of total cholesterol, age, BMI, race, sex, triglycerides, HDL-C, low-density lipoprotein-C, and SBP was conducted for 236 participants (3.1%) with missing baseline data and 201 participants (2.6%) with missing follow-up data.

Participants without at least 1 visit at age  $\geq 30$  years (the age above which Framingham risk score is validated) were excluded and considered unavailable for follow-up. Therefore, inverse probability of censorship weighting was used to correct for bias.<sup>12</sup> First, we created an indicator variable for unavailability for follow-up (1=remained in study; 0=unavailable for follow-up) among all 7624 participants. A multivariable logistic regression model was formed with this indicator variable as the dependent variable. Independent variables in this model were age, sex, race, BMI, total cholesterol, triglycerides, number of visits before unavailability for follow-up, and year of enrollment. This model was assessed using Pearson's goodness-of-fit test and the C-statistic.<sup>13</sup> To

form weights, the inverse of the predicted probabilities from this model was calculated: inverse probability of censorship weighting=(1/inverse of the predicted probabilities). We conducted 2 sensitivity analyses by trimming extreme weights to the 99th percentile and the 95th percentile (Table S2).

Univariate baseline and follow-up characteristics were presented as mean (SD) and/or median (interquartile range [IQR]) for continuous variables (age, BMI, SBP, total cholesterol, HDL-C, low-density lipoprotein-C, triglycerides, year of enrollment, and ICH sum) and as number (percentage) for categorical variables (smoking status and percentage meeting ICH metrics). We conducted bivariate analyses by sex and race, testing differences using Wilcoxon tests (continuous variables) or Pearson's  $\chi^2$  tests (categorical variables). A conservative Bonferroni correction using a factor of 10 was applied to correct for multiplicity.

## Quantifying CRM

To quantify population-level CRM, methods of Chetty et al were adapted.<sup>1</sup> We defined CRM as the rank-rank slope ( $\beta$ ) from the linear regression between childhood cardiovascular risk percentile ranking ( $x$  axis) and adult cardiovascular risk ranking ( $y$  axis). A slope of 0 indicates complete CRM, whereas a slope of 1 indicates that adult relative cardiovascular risk is completely determined by one's childhood risk (ie, no mobility). A major improvement in applying the rank-rank slope method in epidemiological studies versus its typical economic application is the ability to consider additional controls for confounding. Herein, we initially reported crude rank-rank slope by age, race, and sex. On the basis of these results, we adjusted our estimates of rank-rank slope for age, sex, race, and follow-up time using multivariable linear regression. We tested for interactions between rank/age, rank/sex, rank/race, and a 3-way interaction of rank/age/race. Interactions significant at a  $P<0.10$  level were included in the final adjusted model. As a given property of the regression slope ( $\beta$ ), when the SDs of  $X$  and  $Y$  are equal (such is the case comparing our childhood [ $X$ ] and adult [ $Y$ ] percentile rankings) the slope ( $\beta$ ) will equal the correlation coefficient ( $r$ ).<sup>14</sup> It likewise follows that  $\beta^2$  equals the coefficient of determination ( $r^2$ ). Therefore, we used our estimate of  $\beta^2$  to report the percentage of variation in adult cardiovascular risk percentile ranking explained by one's childhood ranking.

## Correlation Between Relative CRM and Absolute CVD Health

To correlate relative CRM with absolute cardiovascular health, we first calculated the individual relative and absolute CRMs of each participant using percentile risk rankings and ICH, respectively. Individual relative CRM is the change in

percentile rankings for each participant from baseline to follow-up. Next, individual relative CRM was used as the independent variable in a linear regression, with CRM as the dependent variable (CRM was defined as change in ICH sum from baseline to adulthood) to determine the effect that relative changes in mobility had on ICH, adjusted for baseline ICH, baseline percentile ranking, and follow-up time. The Pearson's correlation coefficient ( $r$ ) for the full model and the partial correlation coefficient for relative CRM (change in percentile ranks) were reported.<sup>15</sup>

## Results

### Participant Characteristics

In our analytical cohort, 2200 participants contributed 74 585 person-years (median, 35.6 years) (Table 1). Mean (SD) baseline age was 10.1 (3.3) years, and mean (SD) age at follow-up was 43.9 (7.3) years. The study population included 1221 women (55.0%) and 707 black participants (31.9%). Black children had significantly higher total cholesterol, HDL-C, and triglycerides than white children (all  $P<0.001$ ). Boys had lower low-density lipoprotein-C ( $P=0.013$ ) and triglycerides ( $P<0.001$ ) than girls. Mean (SD) BMI was 17.8 (3.6) kg/m<sup>2</sup>, and there were no differences in childhood BMI by sex or race.

### Inverse Probability of Censorship Weighting

All 7624 participants contributed to inverse probability of censorship weighting. This model was well specified, with C-statistic=0.929 (95% confidence interval [CI], 0.923–0.935) and Pearson's goodness-of-fit  $\chi^2$   $P=0.99$ . The median (IQR) weight value was 1.20 (1.03–2.56).

### Adult and Childhood Cardiovascular Risk

Median (IQR) Framingham 10-year risk of coronary heart disease at follow-up was 1.4% (0.4%–4.6%). Risks were higher for men (median, 4.1% [IQR, 1.5%–7.7%]) versus women (median, 0.6% [IQR, 0.2%–1.6%];  $P<0.0001$  for difference). Risks were similar between white (median, 1.5% [IQR, 0.4%–4.8%]) and black (median, 1.3% [IQR, 0.4%–4.2%];  $P=0.24$  for difference) participants. Median (IQR) childhood cardiovascular Z score was  $-0.4$  ( $-1.4$  to  $0.7$ ). Z scores were marginally lower for black participants (median,  $-0.5$  [IQR,  $-1.4$  to  $0.5$ ]) versus white participants (median,  $-0.3$  [IQR,  $-1.4$  to  $0.7$ ];  $P=0.05$  for difference) (Figure S1). Z scores did not differ by sex.

### Absolute Cardiovascular Health

Most children met ideal criteria for smoking (97.7%), fasting blood glucose (98.8%), and SBP (97.3%) (Table 1). White

**Table 1.** Baseline and Follow-Up Characteristics of 2220 BHS Participants

Characteristics	All (N=2200)	Men (n=999 [45.0%])	Women (n=1221 [55.0%])	Blacks (n=707 [31.9%])	Whites (n=1513 [68.1%])	$P_{\text{sex}}$ ; $P_{\text{race}}$ *
<b>Baseline characteristic (childhood visit)</b>						
Age, mean (SD), y	10.1 (3.3)	10.2 (3.4)	10.0 (3.3)	9.9 (3.2)	10.2 (3.4)	0.99; 0.99
BMI, mean (SD), kg/m <sup>2</sup>	17.8 (3.6)	17.8 (3.5)	17.8 (3.7)	17.7 (3.8)	17.8 (3.5)	0.99; 0.99
Systolic blood pressure, mean (SD), mm Hg	99.9 (10.2)	100.6 (10.4)	99.4 (10.0)	99.8 (10.9)	100.0 (9.9)	0.049; 0.99
Total cholesterol, mean (SD), mg/dL	163.6 (28.6)	161.8 (28.9)	165.1 (28.2)	168.1 (28.9)	161.5 (28.2)	0.050; <0.001
HDL-C, mean (SD), mg/dL	65.4 (20.9)	65.9 (20.9)	65.1 (20.9)	70.8 (20.5)	63.0 (20.6)	0.99; <0.001
LDL-C, mean (SD), mg/dL	90.0 (24.0)	88.2 (24.1)	91.5 (23.8)	90.6 (22.9)	89.7 (24.5)	0.013; 0.99
Triglycerides, median (IQR), mg/dL	62 (47–82)	59 (45–79)	64 (48–85)	56 (44–72)	65 (48–87)	<0.001; <0.001
Current smoker ( $\geq 1$ cigarette/week), n (%)	52 (2.3)	30 (3.0)	22 (1.8)	15 (2.1)	37 (2.4)	0.567; 0.99
Year of enrollment, median (IQR)	1974 (1973–1977)	1974 (1973–1976)	1973 (1973–1976)	1974 (1973–1977)	1974 (1973–1977)	0.234; 0.99
<b>Ideal Cardiovascular Health metrics (0=poor; 1=intermediate; 2=ideal)</b>						
Smoking, % ideal	97.7	97.0	98.2	97.9	97.6	0.314; 0.99
BMI, % ideal	82.0	82.8	81.3	83.1	81.4	0.99; 0.867
Cholesterol, % ideal	61.7	64.6	59.3	54.3	65.1	0.193; <0.001
Systolic blood pressure, % ideal	97.3	96.8	97.7	96.5	97.7	0.99; 0.99
Fasting glucose, % ideal	98.8	98.3	99.3	98.6	98.9	0.178; 0.99
Ideal Cardiovascular Health sum, mean (SD) <sup>‡</sup>	9.1 (1.0)	9.2 (1.1)	9.1 (1.0)	9.0 (1.1)	9.2 (1.1)	0.99; 0.016
<b>Follow-up characteristic (adult visit)</b>						
Age, mean (SD), y	43.9 (7.3)	43.7 (7.4)	44.1 (7.2)	44.2 (7.1)	43.8 (7.4)	0.99; 0.99
BMI, mean (SD), kg/m <sup>2</sup>	30.5 (7.7)	30.1 (6.8)	30.8 (8.4)	32.2 (8.9)	29.7 (7.0)	0.207; <0.001
Systolic blood pressure, mean (SD), mm Hg	120.8 (16.4)	124.3 (15.3)	117.9 (16.7)	125.9 (19.2)	118.4 (14.3)	<0.001; <0.001
Total cholesterol, mean (SD), mg/dL	192.6 (40.1)	190.4 (40.8)	194.4 (39.5)	187.3 (41.0)	195.1 (39.5)	0.198; <0.001
HDL-C, mean (SD), mg/dL	50.1 (15.7)	45.2 (14.3)	54.0 (15.6)	53.5 (16.3)	48.4 (15.1)	<0.001; <0.001
LDL-C, mean (SD), mg/dL	118.4 (35.5)	119.6 (36.3)	117.5 (34.9)	113.7 (37.3)	120.7 (34.5)	0.99; <0.001
Triglycerides, median (IQR), mg/dL	110 (76–161)	119 (82–177)	103 (72–146)	93 (67–135)	117 (82–177)	<0.001; <0.001
Current smoker ( $\geq 1$ cigarette/week), n (%)	689 (31.0)	336 (33.6)	353 (28.9)	217 (30.7)	472 (31.2)	0.153; 0.99
Total follow-up, median (IQR), y	35.6 (27.9–40.3)	34.7 (27.6–40.3)	36.2 (28.2–40.4)	35.9 (28.5–40.6)	35.3 (27.6–40.3)	0.738; 0.497
Total follow-up, mean (SD), y	33.9 (7.1)	33.5 (7.2)	34.1 (7.0)	34.3 (6.9)	33.6 (7.2)	

Continued

**Table 1.** Continued

Characteristics	All (N=2200)	Men (n=999 [45.0%])	Women (n=1221 [55.0%])	Blacks (n=707 [31.9%])	Whites (n=1513 [68.1%])	$P_{sex}; P_{race}^*$
Ideal Cardiovascular Health metrics (0=poor; 1=intermediate; 2=ideal)						
Smoking, % ideal	57.5	54.9	59.6	59.8	56.8	0.234; 0.480
BMI, % ideal	24.9	21.4	27.7	22.2	26.1	<0.001; <0.001
Cholesterol, % ideal	61.7	63.2	60.4	66.2	59.6	0.99; 0.005
Systolic blood pressure, % ideal	54.5	43.0	63.8	43.1	59.8	<0.001; <0.001
Fasting glucose, % ideal	65.0	61.1	68.2	60.5	67.1	0.01; 0.040
Ideal Cardiovascular Health sum, mean (SD) <sup>‡</sup>	6.5 (1.9)	6.3 (1.9)	6.7 (1.9)	6.3 (1.8)	6.7 (1.9)	<0.001; <0.001

BMI indicates body mass index; BHS, Bogalusa Heart Study; HDL-C, high-density lipoprotein-cholesterol; IQR, interquartile range; and LDL-C, low-density lipoprotein-cholesterol.

\*Bonferroni-corrected *P* values presented to account for multiple hypothesis testing.

<sup>‡</sup>From the 5 listed Ideal Cardiovascular Health metrics attributable to available data, physical activity and diet are the 2 additional Ideal Cardiovascular Health metrics that we did not analyze.

children had higher ICH sums than black children (9.2 versus 9.0;  $P=0.02$ ) because of a higher percentage meeting the ideal criteria for cholesterol (65.1% versus 54.3%;  $P<0.001$ ). At follow-up, fasting blood glucose remained the most attained ideal ICH metric, with 65.0% of adults meeting the ideal criteria. Mean (SD) ICH sum in adulthood was 6.5 (1.9), although both men and blacks (both means=6.3) had significantly worse ( $P<0.001$ ) ICH than women and whites, respectively (both means=6.7).

### Cardiovascular Risk Mobility

In crude analyses (Table 2), rank-rank slope was similar ( $P=0.79$ ) for men ( $\beta=0.16$  [95% CI, 0.11–0.21]) and women ( $\beta=0.17$  [95% CI, 0.12–0.23]), but was greater ( $P<0.01$ ) for white ( $\beta=0.22$  [95% CI, 0.18–0.27]) versus black ( $\beta=0.10$  [95% CI, 0.03–0.17]) participants, indicating a greater CRM for black participants. Rank-rank slope interacted significantly with age ( $\beta_{age \times slope}$  for change in rank-rank slope with each 1-year increase in age= $-0.03$  [95% CI,  $-0.04$  to  $-0.02$ ];  $P<0.0001$ ).

After multivariable adjustment, age maintained strong interaction with rank-rank slope ( $\beta_{age \times slope}=-0.02$  [95% CI,  $-0.03$  to  $-0.01$ ];  $P<0.001$ ) (Figure 1). Two children separated by 10 percentiles of CVD risk at age 5 years could expect to remain 2.4 percentiles apart as adults. Those same children separated by 10 percentile points at age 15 years would be only 0.7 percentiles apart as adults. The rank-rank slope for black participants ( $\beta=0.10$  [95% CI, 0.05–0.15]) remained lower than for white participants ( $\beta=0.18$  [95% CI, 0.14–0.22];  $P=0.01$ ), and corresponding  $r^2$  values (95% CI) were 0.01 (0.00–0.02) for blacks and 0.03 (0.02–0.05) for whites (Table 2). Interaction between rank/sex was not significant ( $P=0.37$ ).

### Correlation Between Relative CRM and Absolute Cardiovascular Health

Adjusted change in CVD risk percentile ranking was closely associated with change in ICH ( $\beta_{\Delta percentile}=0.041$  [95% CI, 0.039–0.044];  $P<0.0001$ ) (Figure 2). Pearson’s correlation ( $r$ ) for the full model was 0.71 (95% CI, 0.69–0.73), and the partial correlation for change in CVD risk percentile ranking ( $r_{\Delta percentile}$ ) was 0.62 (95% CI, 0.60–0.65).

### Discussion

Using an approach to measure equality that is novel in epidemiological research, we saw substantial mobility in life course cardiovascular risk in our large biracial cohort across 30+ years of follow-up. In the economic sphere, rank-rank

**Table 2.** Unadjusted and Adjusted Rank-Rank Slope by Sex, Race, and Age

Covariate	Rank-Rank Slope (95% Confidence Interval)				$r^2$
	Unadjusted	<i>P</i> Value*	Adjusted <sup>†</sup>	<i>P</i> Value*	
Sex		0.79		0.37	
Female	0.17 (0.12–0.23)		0.15 (0.12–0.19) <sup>‡</sup>		0.02 (0.01–0.04)
Male	0.16 (0.11–0.21)		0.15 (0.12–0.19) <sup>‡</sup>		0.02 (0.01–0.04)
Race		<0.01		0.01	
Black	0.10 (0.03–0.17)		0.10 (0.05–0.15)		0.01 (0.00–0.02)
White	0.22 (0.18–0.27)		0.18 (0.14–0.22)		0.03 (0.02–0.05)
Age, y		<0.0001		<0.001	
5	0.34 (0.27–0.41)		0.24 (0.18–0.29)		0.06 (0.03–0.08)
6	0.31 (0.25–0.37)		0.22 (0.17–0.27)		0.05 (0.03–0.07)
7	0.28 (0.23–0.33)		0.20 (0.16–0.24)		0.04 (0.03–0.06)
8	0.25 (0.21–0.29)		0.19 (0.15–0.22)		0.04 (0.02–0.05)
9	0.22 (0.18–0.26)		0.17 (0.14–0.20)		0.03 (0.02–0.04)
10	0.19 (0.15–0.23)		0.16 (0.13–0.19)		0.03 (0.02–0.04)
11	0.16 (0.12–0.20)		0.14 (0.11–0.17)		0.02 (0.01–0.03)
12	0.13 (0.08–0.18)		0.12 (0.09–0.16)		0.02 (0.01–0.03)
13	0.10 (0.04–0.15)		0.11 (0.06–0.15)		0.01 (0.00–0.02)
14	0.07 (0.00–0.13)		0.09 (0.04–0.14)		0.01 (0.00–0.02)
15	0.04 (–0.04 to 0.11)		0.07 (0.02–0.13)		0.01 (0.00–0.02)

\**P* value for interaction between rank-rank slope and covariate.

<sup>†</sup>Adjusted for sex, race, age, follow-up time, and interaction terms between race/rank and age/rank in an inverse probability of censoring weighted linear regression model.

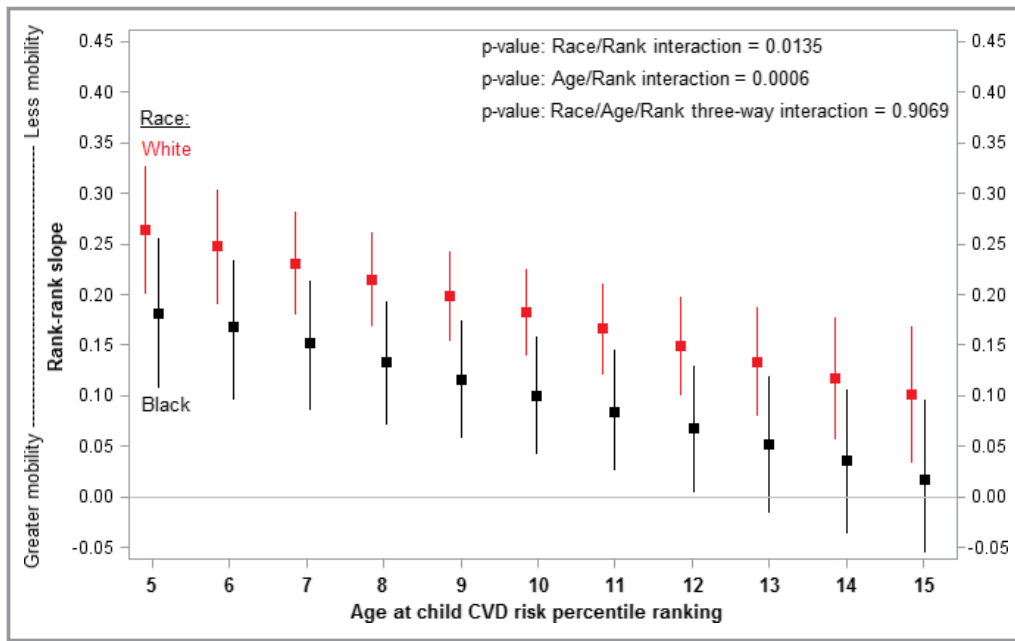
<sup>‡</sup>Adjusted model did not include sex/rank interaction term ( $P=0.37$ ), so the rank-rank slope for both men and women in the adjusted model is identical.

slopes of  $\beta=0.40$  to  $0.50$  denote regions with the worst socioeconomic mobility, whereas rank-rank slopes near  $\beta=0.20$  indicate relatively high socioeconomic mobility. Using New Orleans as our reference commuting zone, Chetty et al reported a rank-rank slope of  $\beta=0.33$  for children in 1980.<sup>1</sup> We can conceptualize that our CRM rank-rank slope of approximately  $\beta=0.15$  (at the mean age of 10.1 years) expresses a much greater level of mobility in cardiovascular risk than in socioeconomic mobility in this region. In fact, only  $\approx 3\%$  of the variation in adult CVD risk percentile ranking was explained by childhood CVD risk percentile.

Our most noteworthy finding was the adverse impact of having a greater risk factor burden relative to one's peers at an early childhood age versus later in childhood. The reason for this effect is likely a mixture of genetics and early environmental factors. A growing body of literature suggests that an earlier age of adiposity rebound, the period in which childhood BMI increases for the second time, is a major risk factor for metabolic syndrome, including later-in-life obesity<sup>16–21</sup> and diabetes mellitus.<sup>22,23</sup> Likewise, research in fetal programming and epigenetics has highlighted the significant effects of early life body composition and environment on later CVD<sup>24–26</sup> and has shown that rapid “catch-up”

weight gain increases the risk of coronary heart disease in adulthood.<sup>27,28</sup> The lower CRM experienced at earlier ages in our study supports these findings and implies 2 additional consequences in light of the report by Olshansky et al that obesity is occurring earlier in childhood and causing a decline in overall life expectancy in the United States.<sup>29</sup> First, life course cardiovascular risk appears to be largely modifiable; thus, the decline in life expectancy is reversible if the correct preventive public health messages are spread effectively. Unfortunately, it has recently been shown that control of CVD has not been spread evenly across the population, but has instead favored those in higher-income brackets.<sup>30</sup> A more widespread and equitable approach at CVD control is still needed. Second, given the early age effect evidenced in our study and the knowledge that obesity is occurring earlier, life course mobility in cardiovascular risk relative to one's peers is likely to decline as well. Thus, we are becoming a nation with unhealthy children who have a decreasing opportunity to catch up to their peers. This unnecessary trend must be avoided by ensuring that children receive proper life course cardiovascular care beginning in the early years of their lives.

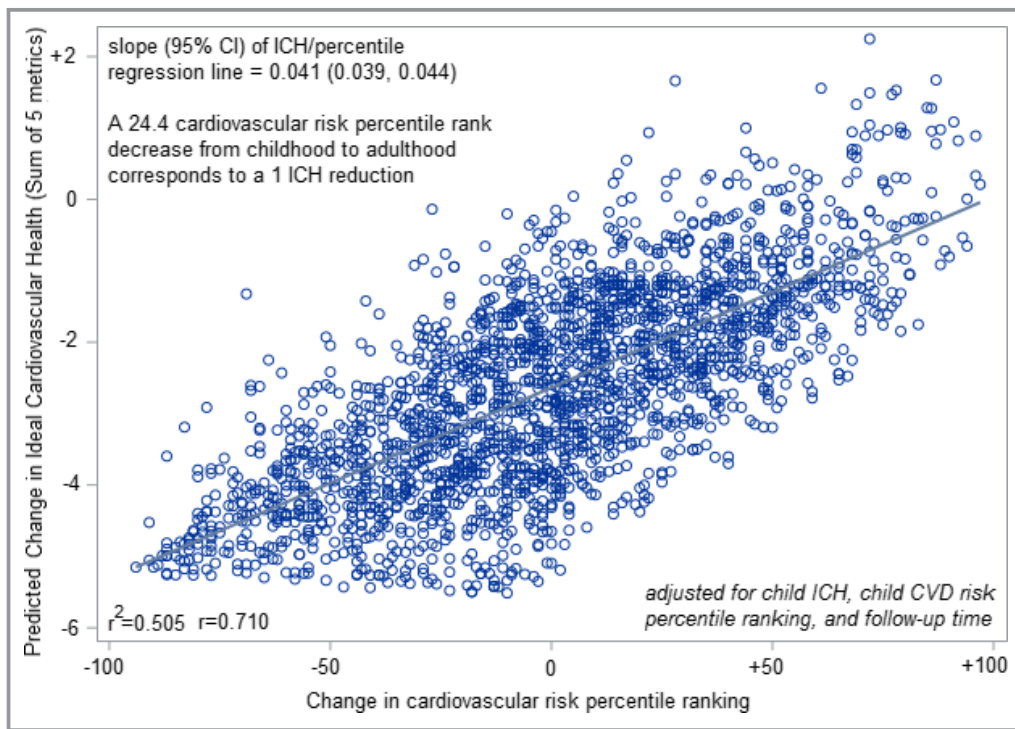
Our analogy between CRM and socioeconomic mobility differs because financial wealth can increase throughout life,



**Figure 1.** Adjusted rank-rank slope by race and age. Adjusted for race, sex, rank, age×rank interaction, race×rank interaction, and follow-up time. CVD indicates cardiovascular disease.

whereas children are generally born with ICH that continually deteriorates throughout life.<sup>31</sup> In addition, relative CRM is arbitrary without knowing the absolute cardiovascular health

of the population. For these reasons, we tested and found strong correlation between relative CRM with ICH, showing that ICH declined for almost everyone from childhood to



**Figure 2.** Correlation between relative cardiovascular risk mobility and ideal cardiovascular disease (CVD) health.  $r=0.710$  indicates Pearson’s correlation coefficient for the full model; partial correlation for change in cardiovascular risk percentile ranking only was  $r=0.62$  (95% confidence interval [CI], 0.60–0.65). ICH indicates Ideal Cardiovascular Health.

adulthood. In our population, a child at the 50th percentile of CVD risk averaged an ICH sum of 9.1 (of 10), declining to a mean of 6.5 in adulthood even if he or she maintained the 50th percentile. If a child at the 50th percentile decreased to the 25th percentile as an adult, he or she experienced an additional loss of 1 ICH point to a mean of 5.5. This additional loss of 1 ICH sum is clinically meaningful, because it corresponds to an adult going from a BMI of 25 to 30 to  $>30 \text{ kg/m}^2$ , or from an SBP in the 120 to 139 range to  $>140 \text{ mm Hg}$ .

Although black participants had slightly better CRM in our population, the difference in effect size was of small magnitude, and resulted in a consistent interpretation that a high level of mobility existed among both races. One possible explanation for the slight discrepancy is our use of the Framingham risk score to measure adult cardiovascular risk. Multiple studies have validated Framingham score in black populations,<sup>32–35</sup> although some have documented that it may underestimate risk among such populations<sup>36</sup> or that its components may affect CVD differentially by race.<sup>37</sup> Regardless, the interaction between age and rank-rank slope was constant across races.

There are some limitations to this study. Unavailability for follow-up is concerning, although we used inverse probability of censorship weighting techniques to diminish the potential for emigrative selection bias. Second, the American College of Cardiology/American Heart Association 10-year atherosclerotic CVD risk score<sup>38</sup> includes race and may be better calibrated for a cohort such as ours. However, atherosclerotic CVD is not validated for adults  $<40$  years, so its use in this study would have mandated further exclusion of a large portion ( $\approx 30\%$ ) of our cohort. Third, regression to the mean from using only a single childhood time point could push the rank-rank slope towards the null, causing our estimates to overstate the true level of mobility. However, we believe regression to the mean is unlikely to have strong influence herein because the child Z score is a composite of 5 individual risk factors. As such, a single extreme residual occurring because of random intrapersonal variation should be limited in its influence when summed with the other 4 residuals to form the Z score. Thus, the Z score functions as a pseudo-repeated measures analysis, which limits the impact of regression to the mean.<sup>39</sup> Last, there is no best method of assessing child cardiovascular risk. Our approach, using a Z score of risk factors used in the Framingham score, is consistent with other studies that have used similar Z scores of cardiometabolic risk factors to assess childhood risk.<sup>8,10</sup> Despite the fact that our measures of childhood and adult risk (Z score and Framingham score, respectively) were calculated from an identical set of risk factors, they differed in their underlying algorithms. Therefore, we cannot be certain that our measure of childhood risk, if unchanged into adulthood (ie, zero

mobility), would have created an identical percentile ranking as calculated by the Framingham score. However, because the Framingham score is validated and clinically meaningful, we believe it to be the appropriate measure to use in adulthood, rather than formulating an adult Z score to match with childhood Z score.

Our novel analysis supports the paradigm that life course CVD risk is almost entirely modifiable. A relatively healthy CVD profile during childhood confers only a minor advantage towards having a relatively low adult CVD risk, although those who fall behind early in childhood must be given special consideration because this substantially reduces their life course CRM. Otherwise, metabolically healthy older children and teenagers should be encouraged to practice preventive CVD behaviors throughout the life course with the same urgency as those with adverse CVD profiles.

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## Disclosures

None.

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# **Supplemental Material**

**Table S1. Characteristics of Ideal Cardiovascular Health<sup>1</sup>**

<b>Ideal Cardiovascular Health</b>	<b>Adults</b>	<b>Children</b>
<b>metric:</b>		
Current smoking		
0 – Poor	Current smoker	Current smoker
1 – Intermediate	Smoker ≤ 12	
2 – Ideal	months Quit > 12 months	Non-smoker
Body mass index		
0 – Poor	≥ 30 kg/m <sup>2</sup>	>95 <sup>th</sup> percentile
1 – Intermediate	25-30 kg/m <sup>2</sup>	85 <sup>th</sup> -95 <sup>th</sup>
2 – Ideal	< 25 kg/m <sup>2</sup>	percentile <85 <sup>th</sup> percentile
Blood glucose		
0 – Poor	≥ 126 mg/dL	≥ 126 mg/dL
1 – Intermediate	100-125 mg/dL	100-125 mg/dL
2 – Ideal	< 100 mg/dL	< 100 mg/dL
Total cholesterol		
0 – Poor	≥ 240 mg/dL	≥ 200 mg/dL
1 – Intermediate	200-239 mg/dL	170-200 mg/dL
2 – Ideal	< 200 mg/dL	< 170 mg/dL
Systolic blood pressure		
0 – Poor	≥ 140 mmHg	>95 <sup>th</sup> percentile

1 – Intermediate	120-139 mmHg	90 <sup>th</sup> -95 <sup>th</sup>
2 – Ideal	< 120 mmHg	percentile <90 <sup>th</sup> percentile
Diet*		
0 – Poor	0-1 components	0-1 components
1 – Intermediate	2-3 components	2-3 components
2 – Ideal	4-5 components	4-5 components
Physical Activity* (minutes per week)		
	None	None
0 – Poor	0-150 minutes	0-60 minutes
1 – Intermediate	≥ 150 minutes	≥ 60 minutes
2 – Ideal		

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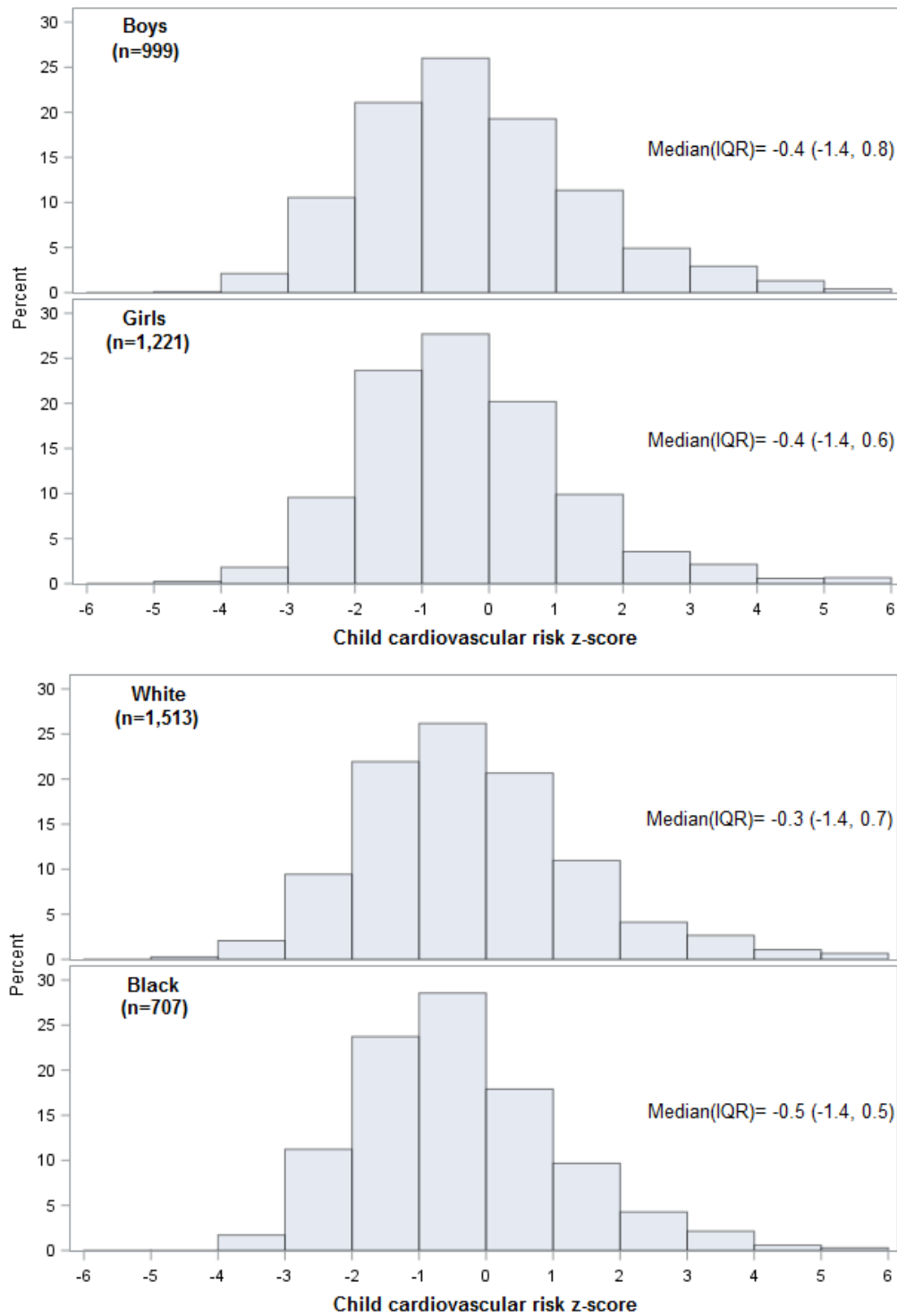
*\*Data on childhood diet and physical activity not available for analysis in our study*

**Table S2. Sensitivity analysis of adjusted<sup>†</sup> rank-rank slope with trimmed (to 95<sup>th</sup> and 99<sup>th</sup> percentiles) inverse probability of censorship weights**

Covariate:	Inverse probability of censorship weight trimming		
	Reported results	95 <sup>th</sup> percentile	99 <sup>th</sup> percentile
Sex			
Female	<b>0.15 (0.12, 0.19)<sup>†</sup></b>	0.15 (0.11, 0.18) <sup>†</sup>	0.14 (0.11, 0.17) <sup>†</sup>
Male	<b>0.15 (0.12, 0.19)<sup>†</sup></b>	0.15 (0.11, 0.18) <sup>†</sup>	0.14 (0.11, 0.17) <sup>†</sup>
Race			
Black	<b>0.10 (0.05, 0.15)</b>	0.12 (0.07, 0.17)	0.10 (0.05, 0.15)
White	<b>0.18 (0.14, 0.22)</b>	0.16 (0.12, 0.19)	0.16 (0.12, 0.20)
Age			
5	<b>0.24 (0.18, 0.29)</b>	0.19 (0.13, 0.24)	0.20 (0.14, 0.26)
6	<b>0.22 (0.17, 0.27)</b>	0.18 (0.13, 0.23)	0.19 (0.14, 0.24)
7	<b>0.20 (0.16, 0.24)</b>	0.17 (0.13, 0.21)	0.18 (0.14, 0.22)
8	<b>0.19 (0.15, 0.22)</b>	0.16 (0.13, 0.20)	0.17 (0.13, 0.20)
9	<b>0.17 (0.14, 0.20)</b>	0.15 (0.12, 0.19)	0.16 (0.12, 0.19)
10	<b>0.16 (0.13, 0.19)</b>	0.15 (0.11, 0.18)	0.14 (0.11, 0.18)
11	<b>0.14 (0.11, 0.17)</b>	0.14 (0.10, 0.17)	0.13 (0.10, 0.17)
12	<b>0.12 (0.09, 0.16)</b>	0.13 (0.09, 0.16)	0.12 (0.08, 0.16)
13	<b>0.11 (0.06, 0.15)</b>	0.12 (0.08, 0.16)	0.11 (0.07, 0.15)
14	<b>0.09 (0.04, 0.14)</b>	0.11 (0.06, 0.16)	0.10 (0.05, 0.15)
15	<b>0.07 (0.02, 0.13)</b>	0.10 (0.04, 0.16)	0.09 (0.03, 0.15)

<sup>†</sup>Adjusted model did not include sex/rank interaction term ( $p=0.37$ ), so the rank-rank slope for both males and females in the adjusted model is identical

**Figure S1. Distribution of childhood z-score by sex and race.**



*p*-value for difference in z-score between boys and girls: *p*=0.30;

*p*-value for difference in z-score by race: *p*=0.05

**Supplemental Reference:**

1. Lloyd-Jones DM, Hong YL, Labarthe D, Mozaffarian D, Appel LJ, Van Horn L, Greenlund K, Daniels S, Nichol G, Tomaselli GF, Arnett DK, Fonarow GC, Ho PM, Lauer MS, Masoudi FA, Robertson RM, Roger V, Schwamm LH, Sorlie P, Yancy CW, Rosamond WD, Plannin AHAS. Defining and Setting National Goals for Cardiovascular Health Promotion and Disease Reduction The American Heart Association's Strategic Impact Goal Through 2020 and Beyond. *Circulation*. 2010;121:586-613.