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Associations of Late Adolescent or Young Adult Cardiovascular Health with Premature Cardiovascular Disease and Mortality

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Abstract

Background: When measured in adolescence or young adulthood, cardiovascular health (CVH) is associated with future subclinical CVD, but data are lacking regarding CVD events or mortality.

Objectives: We examined associations of CVH at age 18–30 years with premature CVD and mortality.

Methods: We analyzed data from the Coronary Artery Risk Development in Young Adults study. CVH was scored at baseline (1985–1986) using Life's Simple 7 metrics and categorized as high (12–14 points), moderate (8–11) or low (0–7). CVD events and cause-specific mortality were adjudicated over 32 years' follow-up. We estimated adjusted associations using Cox models and calculated event rates and population attributable fractions (PAFs) by CVH category.

Results: Among 4,836 participants (mean age 24.9 years, 54.8% female, 50.5% Black, mean education 15.2 years), baseline CVH was high (favorable) in 28.8%, moderate in 65.0%, and low in 6.3%. During follow-up, 306 CVD events and 431 deaths occurred. The adjusted HRs (95% CI) for high (vs low) CVH were 0.14 (0.09–0.22) for CVD and 0.07 (0.03–0.19) for CVD mortality, and the PAFs for moderate/low (vs high) CVH were 0.63 (0.47–0.74) for CVD and 0.81 (0.55–0.92) for CVD mortality. Among individuals with high CVH, event rates were low across sociodemographic subgroups (e.g., CVD rates/1000 person-years: age 18–24, 0.64; age 25–30, 0.65; men, 1.04; women, 0.36; Blacks, 0.90; Whites, 0.50; ≤high-school education, 1.00; >high-school, 0.61).

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Conclusions: High CVH in late adolescence/young adulthood was associated with very low rates of premature CVD and mortality over 32 years, indicating the critical importance of maintaining high CVH.

Condensed abstract: We investigated associations of cardiovascular health (CVH), based on Life's Simple 7, at age 18–30 years with premature CVD and mortality over 32 years. Among 4,836 participants, baseline CVH was high (favorable) in 29%, moderate in 65%, and low in 6%. The adjusted HR for CVD was 0.14 (95% CI, 0.09–0.22) for high (vs low) CVH, and the population attributable fraction for moderate/low (vs high) CVH was 0.63 (0.47–0.74). Among individuals with high CVH, CVD rates were low across subgroups defined by age, sex, race, and education, indicating the potential impact of maintaining high CVH throughout childhood into young adulthood.

Summary Tweet: Favorable cardiovascular health in adolescence or young adulthood was associated with very low rates of premature CVD and mortality over 32 years. Twitter handle for Senior Author: @dmljmd

Keywords

population attributable fraction; Life's Simple 7; primordial prevention

Introduction

When measured in mid-life, cardiovascular health (CVH), as defined by the American Heart Association (AHA) using "Life's Simple 7" metrics,(1) is associated with markedly reduced risks for cardiovascular disease (CVD), mortality, and numerous other adverse health outcomes.(2–4) CVH measured in adolescence or young adulthood has been associated with subclinical CVD,(5–10) but data are lacking regarding associations with future CVD events or mortality. Such data are needed for at least two reasons. First, available data indirectly suggest that young adult CVH may prove a key target to reduce population CVD and mortality burdens and disparities. In the majority of the US population, substantial loss of favorable (high) CVH occurs during youth,(4) and an analysis of midlife CVH found that outcomes were associated primarily with CVH at younger ages, regardless of subsequent CVH change in midlife.(11) Second, for longitudinal studies of early-life determinants of risk, CVH in late adolescence or young adulthood may be a useful intermediate or surrogate endpoint well in advance of hard clinical endpoints that would take decades to accumulate. What is needed, therefore, is quantification of late-adolescent and young-adult CVH associations with subsequent CVD events and mortality.

In this study, we analyzed >30 years of longitudinal data from the Coronary Artery Risk Development in Young Adults Study (CARDIA) to test the following two hypotheses: (1) CVH status in late adolescence or young adulthood (age 18–30 years) is associated with incident premature CVD and mortality, with very low event rates across all sociodemographic subgroups with high CVH; and (2) population attributable fractions (PAFs) for poor CVH status—i.e., the proportion that theoretically would not have occurred if all individuals had high CVH—are high for these premature events.

Methods

Study Design and Participants

CARDIA(12) is a longitudinal cohort study that began in 1985–86 with enrollment of 5,115 healthy young adults, balanced on sex, age (18–24 and 25–30 years), race (Black and White), and education (up to/through and more than high school), at four US sites: Birmingham, Alabama; Chicago, Illinois; Minneapolis, Minnesota; and Oakland, California. A total of 8 in-person follow-up examinations have occurred, most recently 30 years after baseline. Additionally, contact is maintained with participants via telephone, mail, or email every 6 months, with annual interim medical history ascertainment; over the last 5 years, >90% of the surviving cohort members have been directly contacted. The study was approved by institutional review boards at all sites, and participants gave informed consent.

CVH Measurement and Classification

The seven CVH metrics (defined as in eTable 1) were measured at baseline. Dietary intake over the past month was assessed with an interviewer-administered, quantitative diet history.(13) Because this method (versus 24-hour recalls and dietary records) is most useful for ranking individuals according to usual consumption rather than quantifying absolute intakes (i.e., estimate scales may be shifted),(14) we assessed dietary quality by ranking intakes of the 13 Healthy Eating Index-2015 (HEI-2015)(15) components to create a Relative HEI-2015 score for each participant. We retained the 13 components in the HEI-2015, except the added sugars component was replaced with sugar-sweetened beverage intake because the latter was more specifically quantified in CARDIA and is typically utilized in CVH dietary metric scoring.(1) The score range (0–5 or 0–10) for each HEI-2015 component was applied for corresponding quantiles (6 or 11 quantiles, respectively) of intakes, with higher quantiles assigned higher scores for adequacy components and lower scores for moderation components.(16) Total Relative HEI-2015 scores ranged from 0 to 100, as for the HEI-2015(15) and other AHA-recommended dietary pattern scores.(4,17) Physical activity was assessed with interviewer-administered self-report of leisure-time frequency and duration of participation in 13 specific activities over the past 12 months,(18) from which we estimated total hours per week of moderate-to-vigorous activity.(19) Cigarette smoking history was self-reported by questionnaire. Body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2) using standardized measurements by trained study personnel. Blood pressure (average of second and third readings) was measured after 5 minutes seated at rest. Venous blood was drawn after a 12-hour fast and analyzed for total cholesterol and glucose using standard methods.(20) Medication use for hypertension, hypercholesterolemia, and diabetes was self-reported.

We used AHA definitions(1,4) to categorize and score each of the seven CVH metrics as ideal (2 points), intermediate (1 point) or poor (0 points) and summed points across all metrics to create a total CVH score of 0 to 14 points (eTable 1). We classified total CVH scores as high (12–14 points), moderate (8–11) or low (0–7), consistent with prior studies.(21,22) In sensitivity analyses, we (1) classified individuals with a CVH score of 12 but with diabetes or smoking as having moderate CVH, rather than high CVH, given the considerable risk conferred by these factors, and (2) applied alternative thresholds for blood pressure

classification according to the 2017 American College of Cardiology (ACC)/AHA Guidelines(23) (Supplemental Table 1 footnote).

CVD and Mortality Outcomes

The primary outcome of interest was incident CVD, including fatal or nonfatal myocardial infarction (MI), coronary revascularization (non-elective), heart failure, stroke, transient ischemic attack, hospitalized unstable angina, carotid or peripheral arterial disease requiring intervention, or other fatal heart or atherosclerotic disease. Secondary outcomes included the composite of CVD or all-cause mortality, as well as individual outcomes of CVD mortality (including fatal coronary or other heart disease, stroke, or other definite atherosclerotic disease as adjudicated, underlying causes of death), all-cause mortality, MI, coronary revascularization, heart failure, and stroke. Events were reported by participants during annual telephone interviews (with specific inquiry regarding hospitalizations). Deaths were identified on an ongoing basis from family contacts and National Death Index queries; vital status follow-up is thus virtually complete on all participants. Reported events were validated and adjudicated by two members of the CARDIA endpoints committee through medical record review using standard definitions.(24) For the current analysis, adjudication of events was complete through 2017–18, 32 years after baseline. Given the participants' baseline mean age (24.9 years) and age range (18–30 years), all events were considered premature.

Covariates

Age, sex, race, and highest attained educational level (total years achieved across follow-up, as some participants were still pursuing education at baseline at age 18–30 years) were self-reported on questionnaires and included as covariates for adjustment. In a sensitivity analysis, we also adjusted for income 5 years after baseline (not available at baseline in CARDIA).

Statistical Analysis

For the current analyses, we excluded 1 participant who withdrew consent, 2 participants who were transgender, 132 participants with extreme reported caloric intakes (>8000 or <800 kcal/day for men; >6000 or <600 kcal/day for women), and 144 participants who were missing data for one or more of the CVH metrics, for a total analytic sample of 4,836 participants.

Descriptive statistics were calculated. We also calculated crude incidence rates for each outcome across CVH categories. After confirming appropriateness of proportional hazards assumptions, we used Cox proportional hazards regression to estimate hazards ratios (HR) for associations between baseline CVH score or category and incident CVD and mortality outcomes, adjusting for age, sex, race, and education (in years). We also generated Cox adjusted cumulative incidence curves.

We estimated the PAFs of moderate, low, and combined moderate/low (vs high) CVH categories for each outcome over 30 years' follow-up. The PAF estimates the proportion of outcome events attributable to a risk factor—in this case, moderate or low CVH—out of all

events in the population over a certain time interval. To calculate PAF, we used a recently developed method and program that accounts for death as a competing risk.(25–27) The calculation takes into account both the baseline prevalence of the CVH category (moderate or low) in the study population and the strengths of the associations between moderate or low (vs high) CVH and the outcomes (CVD event and death). The strengths of the associations were estimated using piecewise constant hazards models adjusted for baseline age, sex, race, and highest education. PAFs and 95% confidence intervals (CI) were estimated using piecewise constant hazard models with complementary logarithmic transformation.(26,27)

All analyses were repeated in subgroups defined a priori by baseline age (18–24 and 25–30 years), sex, race, and total education level (up to/through high school [≤HS] and beyond high school [>HS]); to preserve sample size, further stratification (e.g., by race-sex group) was not performed. A multiplicative interaction term testing for significant differences in associations of CVH with outcomes across the four race-sex groups (Black men and women, White men and women) was tested in the fully adjusted Cox models and yielded no evidence of effect modification for any outcome. In a secondary analysis, we examined associations between the levels of each of the seven CVH metrics and the primary outcome of CVD using Cox proportional hazards regression with adjustment for age, sex, race, education, and the levels (ideal, intermediate, or poor) of the other CVH metrics. For all analyses, we used SAS version 9.4 (SAS Institute, Cary, NC), with a two-sided significance level of 0.05.

Results

Analytic Sample

Baseline characteristics and CVH levels of the 4,836 included participants are shown in Tables 1 and 2. The mean age was 24.9 (SD 3.6) years and the mean years of education were 15.2 (2.6), with 54.8% women and 50.5% Black participants. CVH was generally more favorable among participants with more than high school education (versus up to/through high school education), among Whites (versus Blacks), and to a lesser extent among those aged 18–24 years (versus 25–30 years) and among women (versus men).

Crude Incidence Rates

During a median follow-up duration of 31.9 years, 306 incident CVD events (at a mean age of 48.7 [SD 6.9] years; 100%/100% at age <65, 97%/98% at age <60, and 82%/81% at age <55 years among men/women) and 431 all-cause deaths (at a mean age of 45.9 [SD 9.8] years) occurred overall (eTable 2 shows outcomes by CVH category). Incidence rates for CVD and mortality outcomes were very low among individuals with high CVH as compared with rates among individuals with moderate or low CVH, both overall and across sociodemographic subgroups (Table 3, Figure 1, eTables 3–6). For example, among individuals with low CVH, CVD rates were 6.27 per 1000 person-years overall and ranged from 4.51 (age 18–24 years) to 8.16 (men) per 1000 person-years among sociodemographic subgroups. Among individuals with high CVH, incident CVD rates were 0.64 per 1000 person-years overall and ranged from 0.36 (women) to 1.04 (men) per 1000 person-years.

Associations between Baseline CVH and Incident Premature CVD and Mortality

In the overall sample, more favorable CVH was significantly associated with lower risks for CVD, mortality, and each CVD subtype (Table 3, Figures 2–3). For the continuous CVH score, the adjusted HR (95% CI) per each 1-point higher CVH score was 0.73 (0.68–0.77) for incident CVD events, and ranged from 0.69 for CVD mortality to 0.80 for all-cause mortality. There were similar findings for all event subtypes (Figure 3). When analyzing categorical levels of CVH, moderate (vs low) CVH was significantly associated with 45% to 73% lower adjusted hazards across all outcomes, and high (vs low) CVH was associated with even lower risk, with 70% to 93% lower adjusted hazards (Table 3). Across sociodemographic subgroups, patterns of association for CVH status were similar, although event numbers were low for some outcomes (Figures 2–3, Supplemental Tables 3-6).

In sensitivity analyses, when participants with diabetes or current smoking were not eligible for “high CVH” status (Supplemental Table 7), when a more restrictive blood pressure classification based on the 2017 ACC/AHA guideline(23) was utilized (Supplemental Table 8), or when additional adjustment for income was performed (Supplemental Table 9), associations of CVH with outcomes were similar to those in the primary analyses.

Population Attributable Fractions for CVD and Mortality by CVH Category

The PAF (95% CI) for CVD associated with combined moderate/low CVH compared with high CVH was 0.63 (0.47–0.74), suggesting that 63% of these premature CVD events would not have happened if all participants had high CVH at baseline. PAFs were significant and high across all events, ranging from 0.42 for premature all-cause mortality to 0.81 for premature CVD mortality (Table 3). PAFs for moderate CVH (alone, vs high CVH) ranged from 0.32 to 0.60 across event types. PAFs for low CVH (alone, vs high CVH) were smaller, ranging from 0.10 to 0.21 across event types, given the low prevalence of low CVH in this young, generally healthy cohort. Across sociodemographic subgroups (Supplemental Tables 3-6), PAFs were not significantly different.

Secondary Analysis: Adjusted Associations of Individual CVH Metrics with CVD

Five of the seven metrics (all but diet and physical activity) were independently associated with CVD after adjustment for sociodemographics and the levels of all other CVH metrics (Supplemental Table 10).

Discussion

Principal Findings

In this community-based, biracial population of 4,836 late adolescents and young adults who were followed for >30 years, several significant findings emerged. First, while this was a younger, asymptomatic, and generally healthy cohort by most standards, more than two-thirds of participants had moderate or worse CVH and only approximately one-fourth had high CVH levels at age 18–30 years. Second, among those with high CVH at baseline, rates of premature CVD events and all-cause mortality were very low (less than 0.2% per year) during long-term follow-up. Third, CVH status in late adolescence/young adulthood was significantly associated with risks for incident premature CVD events and mortality, with

lower hazards by 20–31% per each 1-point higher baseline CVH score. Those with categorical high compared with low CVH at baseline had 70–93% lower risks for premature CVD events or all-cause mortality. Fourth, PAFs for moderate/low (vs high) baseline CVH were high, at 63% for CVD and up to 81% for CVD mortality, suggesting that the vast majority of premature events could have been avoided if all participants had high CVH at baseline. Finally, we observed no significant differences in patterns of findings across sociodemographic subgroups, including sex and race subgroups.

Findings in the Context of Prior Literature

Several prior studies have quantified the association of *mid-life* CVH with later-life CVD events and mortality, and these suggested significant age effects whereby associations were strongest when CVH was measured in younger compared with older middle age. The most recent meta-analysis examining incident CVD events included 12 prospective studies with 210,443 adults at a mean age of 59 years.(28) The pooled HRs (95% CI) for CVD among those with high CVH and intermediate CVH vs low CVH (each defined somewhat differently than in the present study) were 0.23 (0.13–0.34) and 0.45 (0.31–0.58), respectively, with some variability by CVD event subtype. An inverse relationship was observed between the mean age at which CVH was measured (between 52 and 73 years across studies) and the strength of the association with outcomes.(28) In a meta-analysis examining mortality only, including 6 prospective studies with 146,454 adults at mean ages of 46–69 years, the pooled HRs (95% CI) for high CVH vs low CVH (again defined somewhat differently than the present study) were 0.54 (0.41–0.69) for all-cause mortality and 0.30 (0.18–0.51) for CVD mortality.(29) For CVD mortality, associations were significantly stronger when CVH was measured at age <50 years versus ≥50 years.

Fewer studies have examined CVH status at young ages, but these have demonstrated that CVH measured in adolescence or young adulthood is associated with later subclinical CVD, including high-risk carotid and aortic intima-media thickness(5–8) and left ventricular hypertrophy and diastolic dysfunction.(10) Although intima-media thickness,(30,31) left ventricular hypertrophy,(32) and diastolic dysfunction(33,34) are each associated with CVD events and mortality, quantification of the direct relationship of CVH status at young ages with hard clinical outcomes has been lacking. The current analysis of 4,638 adults at a mean age of 25 years provides unique evidence that the relative associations of late-adolescent/young-adult CVH with CVD and mortality appear to be at least as strong as, and possibly stronger than, those for mid-life and later CVH reviewed above. Furthermore, the CVD and mortality events in the current study were premature, occurring in mid-life (<65 years). This deserves emphasis because recent data suggest that rates of such premature heart disease death (i.e., in adults aged 45–64 years) have increased in the US during 2011 to 2017,(35) and the implications of CVH for an individual's healthy life-expectancy in particular (or "healthspan") may be greatest when CVH is measured at younger (vs older) ages.

We also found that CVH measured at age 18–30 years was associated with PAFs for CVD (0.63) and especially for CVD mortality (0.81) that are at least as high as, and in some cases higher than, those for CVH measured in mid-life. In a prior report of data from 13,541 adults at a mean baseline age of 60 years, baseline smoking, obesity, hypertension,

hypercholesterolemia, and diabetes mellitus (5 of the 7 CVH metrics) had a combined PAF of 0.53 (95% CI, 0.47–0.58) for incident CVD over 10 years of follow-up.(36) For mortality, based upon data from 16,215 US adults at a mean age of 45 years, the PAFs (95% CI) for non-ideal CVH (i.e., <7/7 metrics ideal) were 0.64 (0.28–0.84) for CVD mortality and 0.59 (0.33–0.76) for all-cause mortality.(3) Significant effect modification with age was detected such that PAFs for CVD mortality were higher when CVH was measured at age <60 vs ≥60 years (0.90 [0.07–0.99] vs 0.44 [0.10–0.83], interaction P=.016). This age dependency aligns with the finding of higher PAFs for CVD and mortality outcomes associated with baseline CVH in our study population with baseline ages of 18–30 years.

Implications

Thus, the first major implication of the current study is that preservation of high CVH into late adolescence/young adulthood merits further study as a key target for reducing population burdens of, and disparities in, CVD and mortality. The high PAFs associated with CVH at age 18–30 years in the current study correlated with both a high prevalence of moderate/low CVH at baseline and strong associations between CVH and outcomes, suggesting that both primordial prevention of CVH declines during youth and improved detection and treatment of established or emerging risk factors in late adolescence and young adulthood are needed. In the US, CVH levels drop precipitously with age such that the prevalence of high CVH (≥5/7 metrics ideal) is already just 45% at age 12–19 years, declining further to 32% at age 20–39 years, and 10.6% at age 40–59 years.(4) National racial and socioeconomic disparities in these CVH declines were reflected in our study by somewhat less favorable CVH levels in Blacks (vs Whites) and in individuals with education up to/through (vs beyond) high school at age 18–30 years. Other data suggest that social determinants of health must be addressed as root causes of risk factor development and poor control, as well as independent contributors to adverse outcomes.(37,38)

Nevertheless, in the current study, event rates were exceedingly low over >30 years of follow-up across all sociodemographic subgroups when high CVH was present at age 18–30 years. Preservation of CVH through youth into early adulthood may thus be particularly favorable for subsequent prognosis, meriting special focus on primordial prevention throughout childhood and adolescence by public health and pediatric health care initiatives. For young adults with established risk factors, improved systems of healthcare delivery are needed. The 18- to 30-year-old age group is particularly difficult to engage clinically due to gaps in insurance coverage and discontinuity from pediatric to adult care (alongside other major life transitions). Undertreatment of young-adult risk factors is further compounded by clinical guidelines that focus primarily on adults ≥40 years of age or utilize 10-year CVD risk calculators heavily weighted on age.(39) Together, these factors result in low rates of ambulatory care use, preventive health guideline adherence, and awareness, treatment, and control of established risk factors among young adults in the current system.(39–43)

Another major implication of our data is that CVH in late adolescence or young adulthood may serve as a valid intermediate or surrogate outcome for investigations of early-life determinants of premature CVD and mortality risks. Given retention, funding, and various other issues for pediatric studies that take decades to accumulate hard outcomes, such a

strong late-adolescent/young-adult predictor of future events is likely to be valuable in pediatric research.

Strengths and Limitations

Key strengths of this study include the >30-year follow-up of a unique age group and the community-based design with a high proportion of Black participants. This study also had limitations. First, given the young baseline age of participants, only premature events have been captured thus far. Second, a single measurement of CVH (rather than change over time) was utilized in the models; however, the strong associations observed for CVH measured once in young adulthood (despite the likely subsequent CVH losses) highlight the relevance of this period in the life course. Third, no correction was performed for multiple testing, and event numbers were low for some outcomes, particularly for CVD subtypes in subgroup analyses; thus, although results were largely consistent, subgroup analyses should be interpreted cautiously. Fourth, diet and physical activity levels were self-reported; despite use of rigorous, interviewer-administered methods, the resulting imprecision(14,44) along with limited event numbers likely contributed to lack of independent statistical significance for these metrics in the association with CVD. Fifth, despite multivariable adjustment, residual confounding (e.g., due to unmeasured socioeconomic variables) is possible.

Conclusions

In a community-based, biracial cohort of late adolescents and young adults, high CVH at age 18–30 years was strongly associated with low rates of incident premature CVD and mortality over >30 years of follow-up, overall and in all sociodemographic subgroups. Furthermore, moderate and low CVH status in late adolescence and young adulthood had high PAFs for premature CVD events and mortality, indicating the importance of defining strategies to maintain high CVH throughout childhood into young adulthood.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations and acronyms:

ACC	American College of Cardiology

AHA	American Heart Association
BMI	body mass index
CARDIA	Coronary Artery Risk Development in Young Adults Study
CVD	cardiovascular disease
CVH	cardiovascular health
HEI	Health Eating Index
HR	hazard ratio
MI	myocardial infarction
PAF	population attributable fraction

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Clinical Perspectives

Competencies in Medical Knowledge:

Life's Simple 7 factors – a healthy diet, physical activity, non-smoking, body mass index, blood pressure, total cholesterol, and fasting glucose — together contribute to cardiovascular (CV) health. Optimal levels of these factors between the ages of 18 and 30 years is associated with a markedly reduced risk of developing CV disease and mortality later in life. Despite differences in the prevalence of CV health related to age, sex, race and education, most premature CV disease and mortality could be prevented if the risk profile of the entire population were optimized.

Translational Outlook:

Further research is needed to define strategies that optimize risk factors and preserve CV health through childhood and young adulthood.

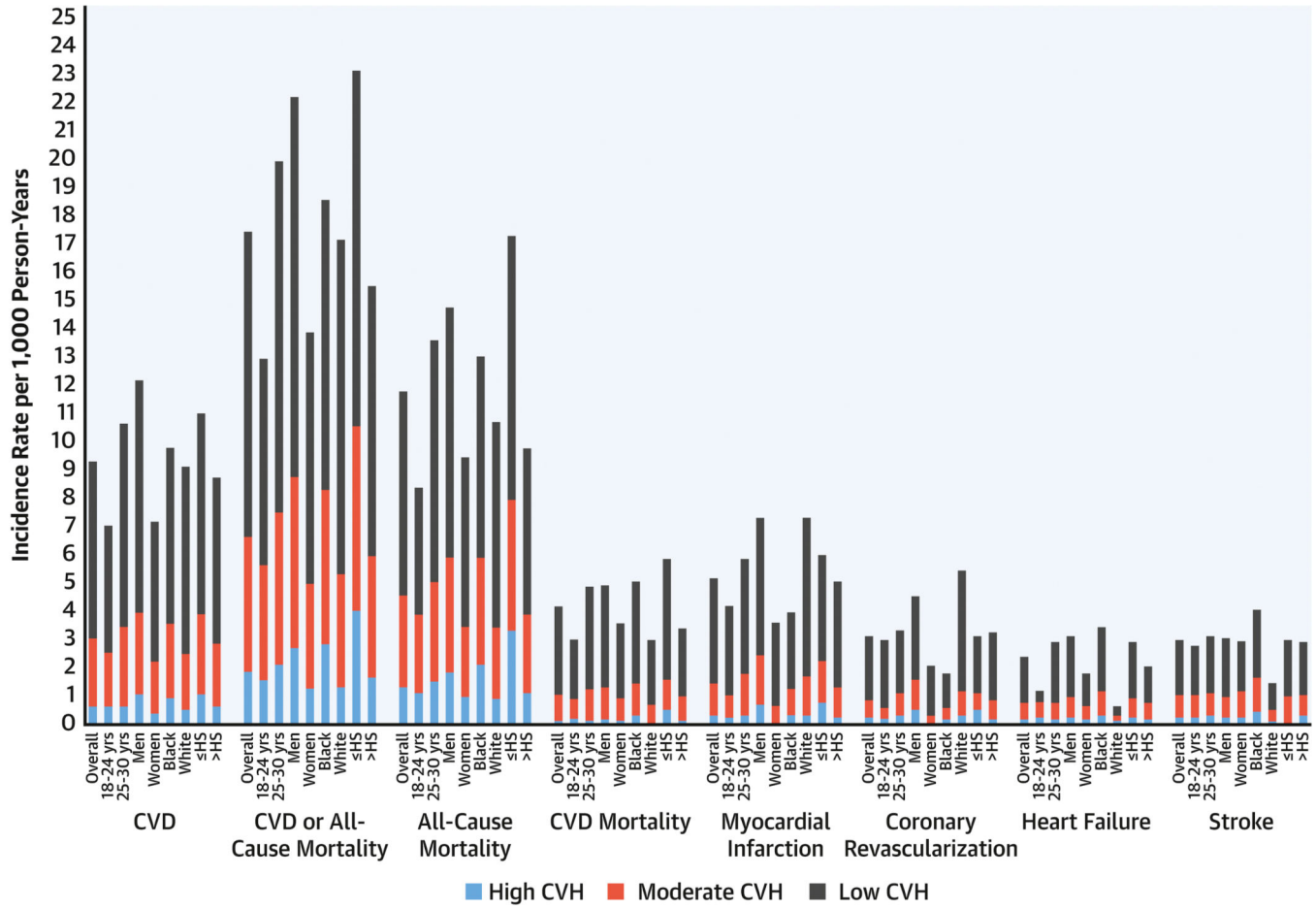


Figure 1. Unadjusted Incident Premature CVD and Mortality Rates by Baseline CVH Category.

Incidence rates were very low during long-term follow-up among individuals with high baseline cardiovascular health (CVH) compared with rates among individuals with low or moderate baseline CVH, both overall and across sociodemographic subgroups. Cardiovascular disease (CVD) includes myocardial infarction, heart failure, stroke, transient ischemic attack, hospitalized unstable angina, carotid or peripheral arterial disease requiring intervention, or other fatal heart or atherosclerotic disease. For CVD death, underlying causes of death included coronary or other heart disease, stroke, or other definite atherosclerotic disease. HS, high school education.

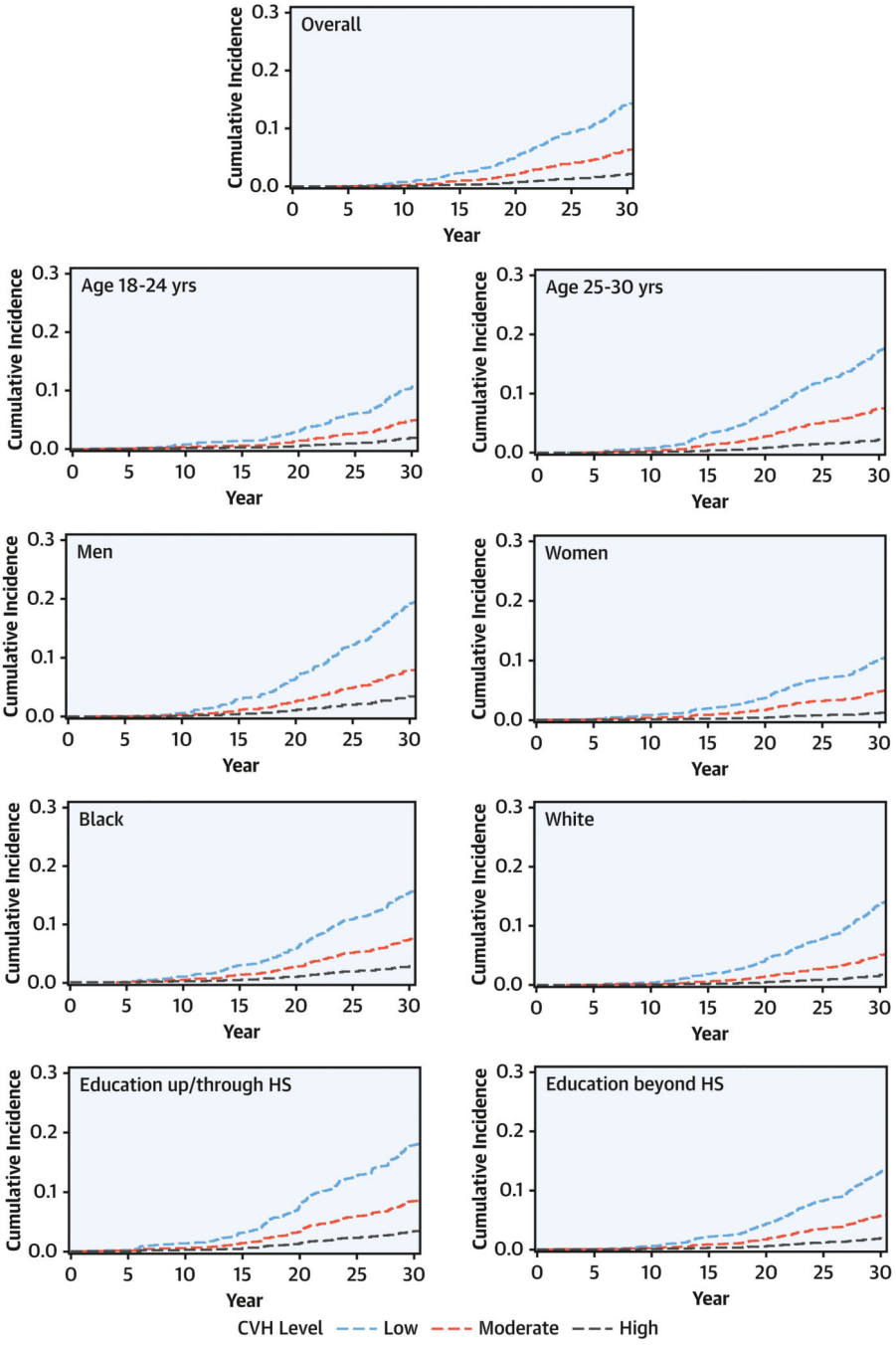


Figure 2. Adjusted CVD Cumulative Incidence Curves by CVH Level at Age 18–30 Years.
In Cox models adjusted for field center, sex, age, race, and total education, more favorable cardiovascular health (CVH) was associated with significantly lower probability of cardiovascular disease (CVD) over 30 years, overall and across sociodemographic subgroups. CVD was defined as in Figure 1. HS, high school.

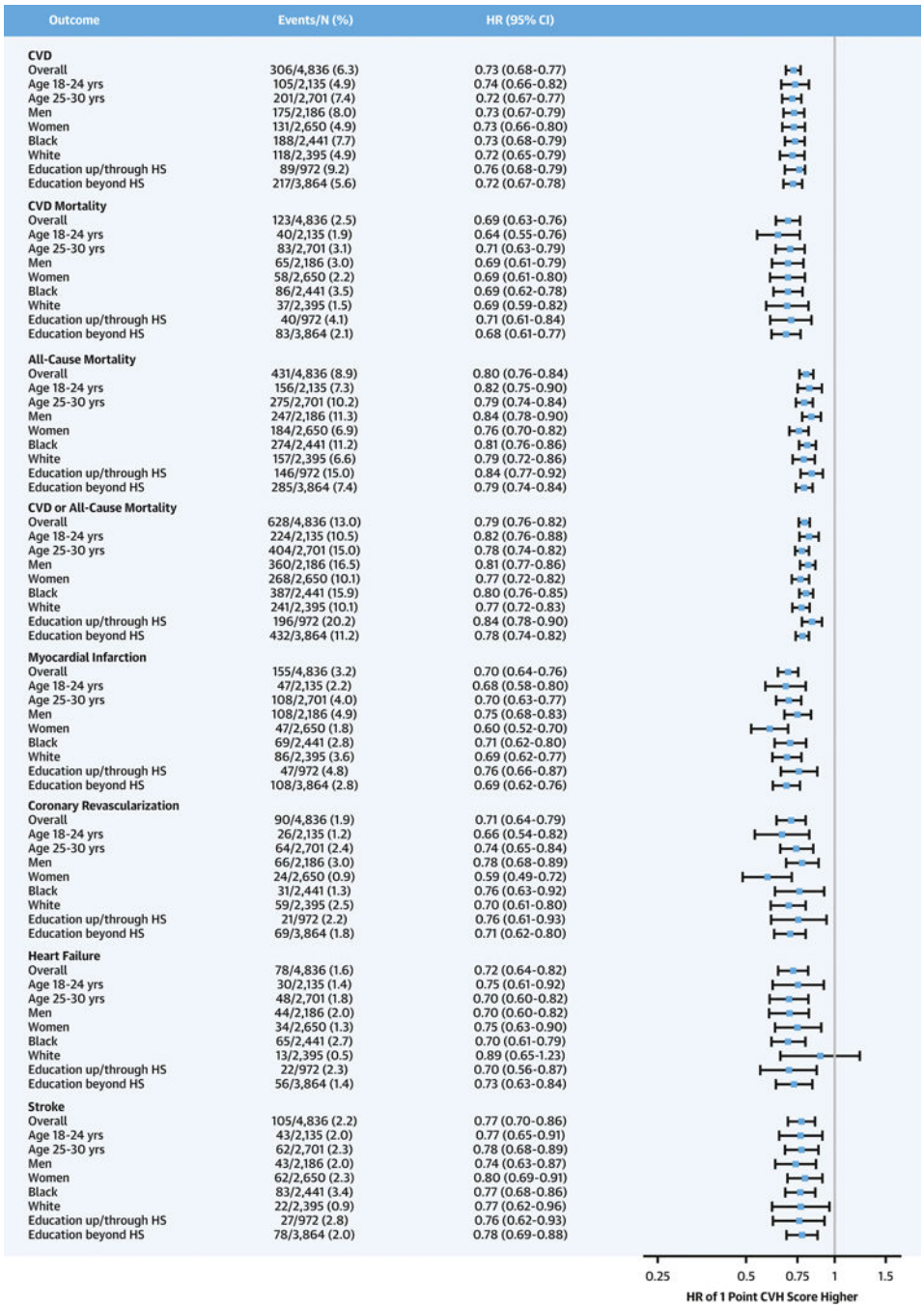
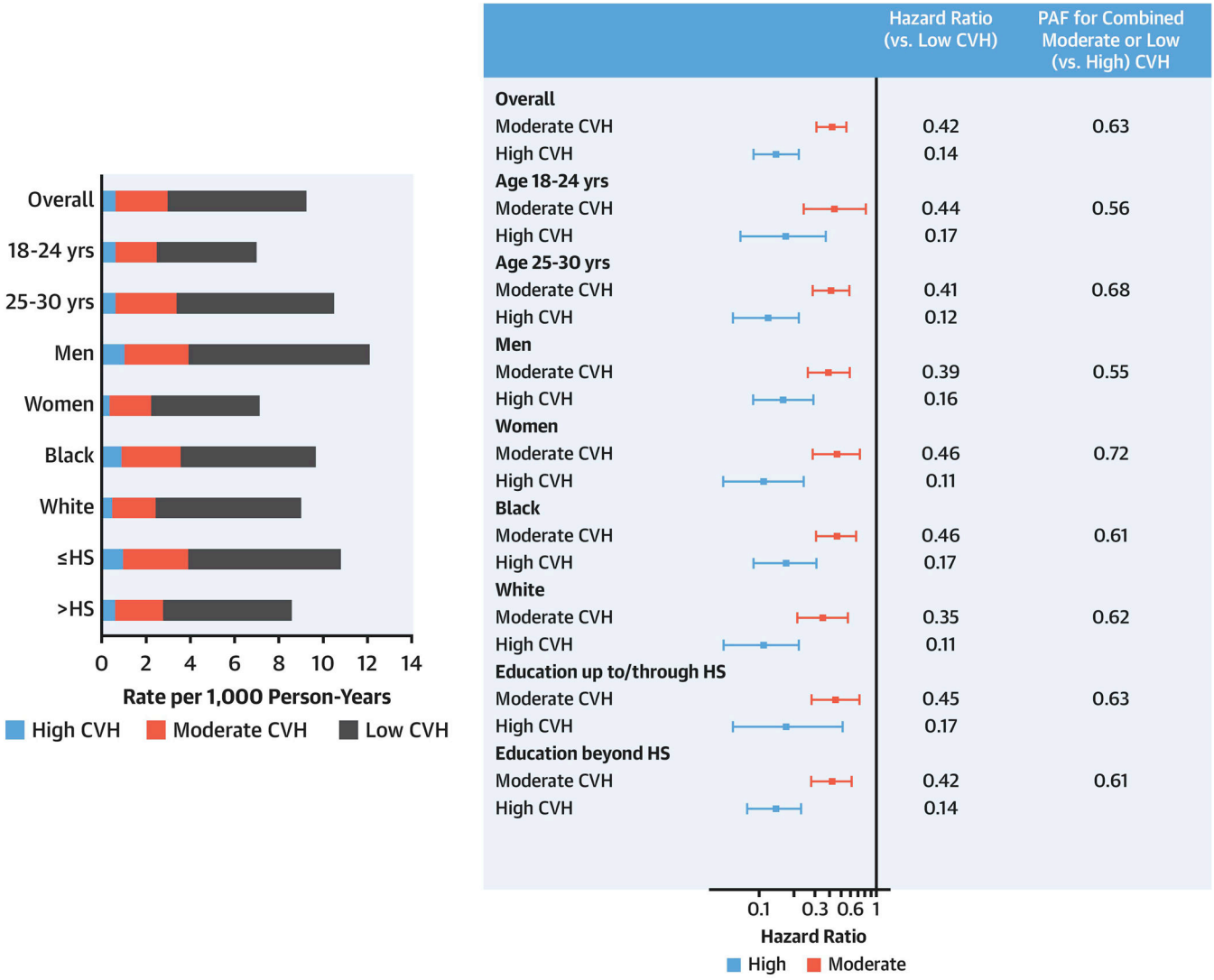


Figure 3. Adjusted Associations between Baseline CVH Score (per 1 Point Higher) and Incident Premature CVD and Mortality.

In Cox models adjusted for field center, sex, age, race, and total education, each 1-point higher baseline cardiovascular health (CVH) score was associated with 20–31% lower hazards for incident premature cardiovascular disease (CVD) and mortality. Findings were similar across sociodemographic subgroups. CVD and CVD death were defined as in Figure 1. Edu, education; HR, hazard ratio; HS; high school; yrs, years.



Central Illustration. Implications of Cardiovascular Health at Age 18 to 30 Years for Incident Premature Cardiovascular Disease Over >30 Years.

In the bar graph (top), unadjusted cardiovascular disease (CVD) incidence rates were very low among individuals with high baseline cardiovascular health (CVH) in all sociodemographic subgroups. In the forest plot (bottom left), after adjustment for field center, sex, age, race, and total education, categorically moderate (vs low) CVH was associated with 58% lower hazard for CVD, and high (vs low) CVH was associated with 86% lower hazard for CVD. The population attributable fraction (bottom right) of CVD was 63% for moderate/low (vs high) baseline CVH. Findings were similar across sociodemographic subgroups. CVD was defined as in Figure 1. Edu, education; HR, hazard ratio; HS, high school; yrs, years.

Table 1.

Baseline Participant Characteristics

	Overall	Age		Sex		Race		Education	
		18–24 Years	25–30 Years	Men	Women	Black	White	≤ HS	> HS
N (%)	4836	2135 (44.1)	2701 (55.9)	2186 (45.2)	2650 (54.8)	2441 (50.5)	2395 (49.5)	972 (20.1)	3864 (79.9)
Age, years	24.9 (3.6)	21.4 (2.0)	27.7 (1.7)	24.9 (3.6)	24.9 (3.7)	24.4 (3.8)	25.4 (3.4)	24.3 (3.8)	25.0 (3.6)
Female, N (%)	2650 (54.8)	1165 (54.6)	1485 (55.0)	-	-	1383 (56.7)	1267 (52.9)	454 (46.7)	2196 (56.8)
Black, N (%)	2441 (50.5)	1242 (58.2)	1199 (44.4)	1058 (48.4)	1383 (52.2)	-	-	665 (68.4)	1776 (46.0)
>HS Education, N (%)	3864 (79.9)	1651 (77.3)	2213 (81.9)	1668 (76.3)	2196 (82.9)	1776 (72.8)	2088 (87.2)	-	-
Total Education, years *	15.2 (2.6)	14.9 (2.5)	15.5 (2.7)	15.1 (2.7)	15.3 (2.6)	14.4 (2.3)	16.1 (2.7)	11.7 (0.7)	16.1 (2.2)
HEI-2015 Diet Score	50 (14)	47 (13)	53 (14)	47 (12)	53 (14)	47 (12)	54 (14)	44 (12)	52 (13)
Physical Activity, hrs/wk †	2.3 (2.3)	2.5 (2.3)	2.2 (2.2)	2.9 (2.5)	1.8 (1.9)	2.2 (2.3)	2.4 (2.3)	2.0 (2.1)	2.4 (2.3)
Cigarettes per day	0 (0–10.0)	0 (0–7.0)	0 (0–10.0)	0 (0–10.0)	0 (0–10.0)	0 (0–7.0)	0 (0–10.0)	5.0 (0–15.0)	0 (0–7.0)
Body Mass Index, kg/m²	24.5 (5.0)	24.1 (4.9)	24.8 (5.1)	24.4 (3.9)	24.6 (5.8)	25.3 (5.7)	23.6 (4.1)	24.7 (5.3)	24.4 (5.0)
Systolic BP, mm Hg	110 (11)	110 (10)	110 (11)	115 (10)	107 (10)	111 (11)	109 (11)	112 (11)	110 (11)
Diastolic BP, mm Hg	69 (10)	67 (9)	70 (10)	71 (10)	67 (9)	69 (10)	68 (9)	68 (11)	69 (9)
BP Medication Use	108 (2.2)	19 (0.9)	89 (3.3)	43 (2.0)	65 (2.5)	76 (3.1)	32 (1.3)	32 (3.3)	76 (2.0)
Total Cholesterol, mg/dL	177 (33)	172 (33)	181 (34)	176 (35)	177 (33)	178 (34)	176 (32)	176 (36)	177 (33)
HDL Cholesterol, mg/dL	53 (13)	52 (13)	54 (14)	50 (13)	56 (13)	54 (13)	52 (13)	52 (14)	53 (13)
LDL Cholesterol, mg/dL	109 (31)	106 (30)	112 (31)	110 (32)	108 (31)	110 (32)	109 (30)	108 (33)	110 (31)
Triglycerides, mg/dL	73 (48)	69 (39)	76 (54)	80 (57)	67 (37)	66 (37)	79 (56)	77 (53)	72 (47)
Lipid Medication Use	0	0	0	0	0	0	0	0	0
Fasting Glucose, mg/dL	83 (16)	82 (14)	83 (17)	84 (14)	81 (17)	82 (19)	83 (12)	83 (16)	82 (16)
Diabetes Medication Use	40 (0.8)	12 (0.6)	28 (1.0)	12 (0.6)	28 (1.1)	27 (1.1)	13 (0.5)	11 (1.1)	29 (0.8)

Continuous variables are shown as mean (SD) or median (IQR); categorical variables are shown as N (%).

*Education is the total attained across follow-up, as some participants were still pursuing education at the time of the baseline examination at age 18–30 years.

†Hours per week of moderate-to-vigorous leisure-time activity.

BP, blood pressure; HDL, high-density lipoprotein; HEI, Healthy Eating Index; HS, high school; hrs, hours; LDL, low-density lipoprotein; wk, week.

Table 2.

Baseline Cardiovascular Health Status

	Overall	Age		Sex		Race		Education	
		18–24 Years	25–30 Years	Men	Women	Black	White	≤HS	>HS
Diet									
Ideal	97 (2.0)	27 (1.3)	70 (2.6)	10 (0.5)	87 (3.3)	21 (0.9)	76 (3.2)	6 (0.6)	91 (2.4)
Intermediate	3644 (75.4)	1478 (69.2)	2166 (80.2)	1548 (70.8)	2096 (79.1)	1704 (69.8)	1940 (81.0)	590 (60.7)	3054 (79.0)
Poor	1095 (22.6)	630 (29.5)	465 (17.2)	628 (28.7)	467 (17.6)	716 (29.3)	379 (15.8)	376 (38.7)	719 (18.6)
Physical Activity									
Ideal	1820 (37.6)	879 (41.2)	941 (34.8)	1046 (47.9)	774 (29.2)	877 (35.9)	943 (39.4)	316 (32.5)	1504 (38.9)
Intermediate	2361 (48.8)	1021 (47.8)	1340 (49.6)	954 (43.6)	1407 (53.1)	1165 (47.7)	1196 (49.9)	468 (48.2)	1893 (49.0)
Poor	655 (13.5)	235 (11.0)	420 (15.6)	186 (8.5)	469 (17.7)	399 (16.4)	256 (10.7)	188 (19.3)	467 (12.1)
Smoking									
Ideal	3125 (64.6)	1402 (65.7)	1723 (63.8)	1394 (63.8)	1731 (65.3)	1530 (62.7)	1595 (66.6)	423 (43.5)	2702 (69.9)
Intermediate	280 (5.8)	118 (5.5)	162 (6.0)	121 (5.5)	159 (6.0)	114 (4.7)	166 (6.9)	53 (5.5)	227 (5.9)
Poor	1431 (29.6)	615 (28.8)	816 (30.2)	671 (30.7)	760 (28.7)	797 (32.7)	634 (26.5)	496 (51.0)	935 (24.2)
Body Mass Index									
Ideal	3157 (65.3)	1473 (69.0)	1684 (62.4)	1406 (64.3)	1751 (66.1)	1431 (58.6)	1726 (72.1)	611 (62.9)	2546 (65.9)
Intermediate	1111 (23.0)	443 (20.8)	668 (24.7)	603 (27.6)	508 (19.2)	602 (24.7)	509 (21.3)	229 (23.6)	882 (22.8)
Poor	568 (11.8)	219 (10.3)	349 (12.9)	177 (8.1)	391 (14.8)	408 (16.7)	160 (6.7)	132 (13.6)	436 (11.3)
Blood Pressure *									
Ideal	3648 (75.4)	1659 (77.7)	1989 (73.6)	1365 (62.4)	2283 (86.2)	1775 (72.7)	1873 (78.2)	701 (72.1)	2947 (76.3)
Intermediate	1083 (22.4)	451 (21.1)	632 (23.4)	748 (34.2)	335 (12.6)	600 (24.6)	483 (20.2)	242 (24.9)	841 (21.8)
Poor	105 (2.2)	25 (1.2)	80 (3.0)	73 (3.3)	32 (1.2)	66 (2.7)	39 (1.6)	29 (3.0)	76 (2.0)
Total Cholesterol									
Ideal	3727 (77.1)	1750 (82.0)	1977 (73.2)	1693 (77.5)	2034 (76.8)	1839 (75.3)	1888 (78.8)	744 (76.5)	2983 (77.2)
Intermediate	898 (18.6)	323 (15.1)	575 (21.3)	388 (17.8)	510 (19.3)	488 (20.0)	410 (17.1)	176 (18.1)	722 (18.7)
Poor	211 (4.4)	62 (2.9)	149 (5.5)	105 (4.8)	106 (4.0)	114 (4.7)	97 (4.1)	52 (5.4)	159 (4.1)
Glucose									
Ideal	4684 (96.9)	2086 (97.7)	2598 (96.2)	2114 (96.7)	2570 (97.0)	2362 (96.8)	2322 (97.0)	930 (95.7)	3754 (97.2)
Intermediate	123 (2.5)	39 (1.8)	84 (3.1)	61 (2.8)	62 (2.3)	62 (2.5)	61 (2.6)	34 (3.5)	89 (2.3)

	Overall	Age		Sex		Race		Education	
		18–24 Years	25–30 Years	Men	Women	Black	White	≤HS	>HS
Poor	29 (0.6)	10 (0.5)	19 (0.7)	11 (0.5)	18 (0.7)	17 (0.7)	12 (0.5)	8 (0.8)	21 (0.5)
Total CVH Score[†]	10.3 (1.8)	10.5 (1.7)	10.2 (1.8)	10.3 (1.7)	10.4 (1.8)	10.0 (1.8)	10.7 (1.7)	9.5 (1.8)	10.5 (1.7)
CVH Category									
High	1391 (28.8)	646 (30.3)	745 (27.6)	590 (27.0)	801 (30.2)	505 (20.7)	886 (37.0)	132 (13.6)	1259 (32.6)
Moderate	3141 (65.0)	1394 (65.3)	1747 (64.7)	1463 (66.9)	1678 (63.3)	1739 (71.2)	1402 (58.5)	717 (73.8)	2424 (62.7)
Low	304 (6.3)	95 (4.5)	209 (7.7)	133 (6.1)	171 (6.5)	197 (8.1)	107 (4.5)	123 (12.7)	181 (4.7)

Data are shown as N (%).

[*] Using the primary blood pressure definition, as shown in eTable 1.

[†] Range of CVH scores, 0–14 points.

CVH, cardiovascular health; HS, high school.

Table 3.

Event Rates, Adjusted* Hazard Ratios, and Population Attributable Fractions for Incident Premature Cardiovascular Disease† Events and Mortality, Overall

	N of Events	Crude Incidence Rate per 1,000 Person-Years			Adjusted* Hazard Ratio (95% CI), versus Low CVH		Population Attributable Fraction (95% CI), versus High CVH		
		Low CVH	Moderate CVH	High CVH	Moderate CVH	High CVH	Moderate CVH	Low CVH	Moderate/Low CVH
CVD†	306	6.27	2.34	0.64	0.42 (0.31–0.57)	0.14 (0.09–0.22)	0.48 (0.34–0.59)	0.15 (0.11–0.19)	0.63 (0.47–0.74)
CVD† Mortality	123	3.08	0.93	0.11	0.40 (0.26–0.61)	0.07 (0.03–0.19)	0.60 (0.41–0.73)	0.21 (0.13–0.28)	0.81 (0.55–0.92)
All-Cause Mortality	431	7.15	3.19	1.30	0.55 (0.42–0.73)	0.30 (0.21–0.44)	0.32 (0.18–0.43)	0.10 (0.07–0.13)	0.42 (0.26–0.54)
CVD† or All-Cause Mortality	628	10.71	4.76	1.84	0.52 (0.41–0.65)	0.25 (0.18–0.34)	0.36 (0.26–0.45)	0.11 (0.08–0.13)	0.47 (0.35–0.56)
Myocardial Infarction	155	3.71	1.14	0.28	0.32 (0.21–0.48)	0.08 (0.04–0.17)	0.51 (0.33–0.64)	0.19 (0.13–0.25)	0.70 (0.49–0.83)
Coronary Revascularization	90	2.23	0.63	0.21	0.27 (0.16–0.46)	0.09 (0.04–0.20)	0.45 (0.20–0.62)	0.20 (0.11–0.28)	0.65 (0.34–0.81)
Heart Failure	78	1.55	0.59	0.16	0.47 (0.26–0.85)	0.19 (0.07–0.48)	0.43 (0.07–0.65)	0.14 (0.04–0.22)	0.57 (0.12–0.79)
Stroke	105	1.88	0.81	0.23	0.51 (0.30–0.87)	0.19 (0.08–0.42)	0.46 (0.18–0.65)	0.12 (0.05–0.19)	0.59 (0.25–0.77)

*Adjusted for field center, sex, age, race, and education (total cumulative, in years).

†CVD includes myocardial infarction, heart failure, stroke, transient ischemic attack, hospitalized unstable angina, carotid or peripheral arterial disease requiring intervention, or other fatal heart or atherosclerotic disease. For CVD death, underlying causes of death included coronary or other heart disease, stroke, or other definite atherosclerotic disease.

CI, confidence interval; CVD, cardiovascular disease; CVH, cardiovascular health.