Dynamic Change of Cardiovascular Health Metrics and Long-Term Risk of Sudden Cardiac Death: The ARIC Study

Yuan-Sheng Zhai, MD*; Wen-Tao Bi, MD*; Zhu-Yu Li, MD, PhD; Li-ping Qu, MD*; Yu-He Jia, MD, PhD; Yun-Jiu Cheng, MD, PhD

BACKGROUND: The change of cardiovascular health (CVH) status has been associated with risk of cardiovascular disease. However, no studies have explored the change patterns of CVH in relation to risk of sudden cardiac death (SCD). We aim to examine the link between baseline CVH and change of CVH over time with the risk of SCD.

METHODS AND RESULTS: Analyses were conducted in the prospective cohort ARIC (Atherosclerosis Risk in Communities) study, started in 1987 to 1989. ARIC enrolled 15,792 individuals 45 to 64 years of age from 4 US communities (Forsyth County, North Carolina; Jackson, Mississippi; suburbs of Minneapolis, Minnesota; and Washington County, Maryland). Subjects with 0 to 2, 3 to 4, and 5 to 7 ideal metrics of CVH were categorized as having poor, intermediate, or ideal CVH, respectively. Change in CVH over 6 years between 1987 to 1989 and 1993 to 1995 was considered. The primary study outcome was physician adjudicated SCD. The study population consisted of 15,026 subjects, of whom 12,207 had data about CVH change. Over a median follow-up of 23.0 years, 583 cases of SCD were recorded. There was a strong inverse association between baseline CVH metrics and time varying CVH metrics with risk of SCD. Compared with subjects with consistently poor CVH, risk of SCD was lower in those changed from poor to intermediate/ideal (hazard ratio [HR], 0.67 [95% CI, 0.48–0.94]), intermediate to poor (HR, 0.73 [95% CI, 0.54–0.99]), intermediate to ideal (HR, 0.49 [95% CI, 0.24–0.99]), ideal to poor/intermediate CVH (HR, 0.23 [95% CI, 0.10–0.52]), or those with consistently intermediate (HR, 0.49 [95% CI, 0.36–0.66]) or consistently ideal CVH (HR, 0.31 [95% CI, 0.13–0.76]). Similar results were also observed for non-SCD.

CONCLUSIONS: Compared with consistently poor CVH, other patterns of change in CVH were associated with lower risk of SCD. These findings highlight the importance of promotion of ideal CVH in the primordial prevention of SCD.

Key Words: benchmarking ■ follow-up studies ■ Minnesota ■ Mississippi ■ North Carolina ■ prospective studies ■ quality indicators, health care

Sudden cardiac death (SCD) has been recognized as a global public health burden, accounting for 15% to 20% of the total mortality around the world annually.1 Current guidelines on prevention of SCD focus primarily on the application of implantable cardioverter-defibrillator in severe heart failure with reduced ejection fraction.2 Nevertheless, only one-quarter of SCD cases occurred in this high-risk patient group, and thus a majority of SCD cases were not addressed.3 Primordial prevention strategies applicable to general population at low risk are warranted to reduce the public burden of SCD-related mortality. Encouragingly, previous epidemiological studies have identified that traditional cardiovascular risk factors (eg, smoking, hypertension, and diabetes) might contribute to the development and occurrence of SCD.4,5 Nevertheless, greater levels of physical activity and healthy diet could reduce the future risk of SCD.6-8
Since 2010, the American Heart Association has advocated following a simplified 7-item tool, also known as Life’s Simple 7, to help improve cardiovascular health (CVH) and reduce cardiovascular mortality in general population. These CVH metrics incorporated measurements of both biological factors (eg, ideal levels of total cholesterol, blood glucose, and blood pressure) and lifestyle behaviors (eg, nonsmoking, and ideal levels of diet, body mass index [BMI], and physical activity). Recent community-based studies have consistently reported that higher CVH metrics were associated with lower risk of incident cardiovascular events and mortality. However, the association between CVH metrics and risk of SCD remains unclear. In addition, as the CVH could change over time, how these changes are related to SCD is largely unknown.

In the present study, we analyzed data from ARIC (Atherosclerosis Risk in Communities) study with the following aims: (1) to estimate the link between baseline CVH and time varying CVH during follow-up with the risk of SCD; (2) to describe change in CVH in 6 years; and (3) to quantify the association of change in CVH with subsequent SCD.

METHODS
The data that support the findings of this study are available from the corresponding author on reasonable request.
deaths were not considered as SCD, when there was evidence of acute noncardiac disease that could explain death and conditions apparently unrelated to arrhythmia, such as car accident, drug overdose, cancer, massive blood loss, pneumonia, acute pulmonary embolism, myocardial rupture after myocardial infarction, stroke, and ruptured aortic aneurysm. The secondary outcome was non-SCD (NSCD) defined as cardiovascular death not meeting SCD criteria.

Statistical Analysis

Baseline and Time-Varying Analysis

The follow-up of events began from the 1987 to 1989 baseline visit. Baseline and time varying CVH status, each individual metric, number of metrics at ideal levels, and overall CVH score between 1987 to 1989 and 1996 to 1998 were used in Cox proportional hazard regression. For the time-varying analysis, cases of SCD/NSCD at each visit (1987–1989, 1990–1992, 1993–1995, and 1996–1998) was identified, and CVH exposure present at the visit just before the event was applied to investigate the relationship. When there was missing CVH exposure, we used the last observation carried forward approach. In addition, restricted cubic spline models were used to visualize the relationship of time varying CVH to the risk of SCD/NSCD. Incidence rate and 95% CIs were estimated with the use of Poisson regression models.

Change of CVH Between 1987 to 1989 and 1993 to 1995 and Subsequent Risk of SCD/NSCD

In this analysis, the follow-up of events began from the 1993 to 1995 visit. As some of the groups were small, 7 categories of change were considered: consistently poor; poor to intermediate/ideal; intermediate to poor; consistently intermediate; intermediate to ideal; ideal to poor/intermediate; and consistently ideal. Kaplan–Meier curves of SCD and NSCD across the 7 categories of change in CVH were compared with the log-rank test. We first calculated the hazard ratio (HR) and 95% CI for each category of overall CVH change using Cox proportional hazards model and the consistently poor CVH group as the reference. Second, we estimated the association between change in the number of ideal metrics and 14-point CVH score with SCD/NSCD. We then repeated the change individual CVH analysis with both outcomes.

Potential covariates adjusted in all Cox models were age, race, sex, education, income, history of coronary heart disease, and use of cardiovascular medications at baseline. In the analysis of change in the number of ideal CVH metrics or in the 14-point CVH score, we further adjusted for the baseline number of ideal metrics and CVH score. Missing values on all socio-demographic covariates were imputed by Markov Chain Monte Carlo multiple imputation method before their inclusion in the full adjusted models.26,27 The proportional hazard assumption of the Cox models was assessed by visual inspection of the survival curves and using Schoenfeld residuals. The linearity assumption for the models with the number of ideal metrics and the 14-point CVH score as continuous exposures was assessed by comparing the Akaike information criterion of linear models with models including quadratic and cubic terms.28

In sensitivity analyses, the modification effect of sex and race in the association between change in categories of CVH and SCD and NSCD was explored by including a corresponding interaction term in the models. In addition, we repeated the change in overall CVH analysis with SCD and NSCD using competing risk analysis by calculating subdistribution HRs using the Fine and Gray method.28 We used Stata version 15.0 (StataCorp, College Station, TX) for all analyses. Statistical tests were 2-sided and used a significance level of P<0.05.

RESULTS

Participant Characteristics

The clinical characteristics of the study participants from visit 1 to visit 4 were presented in Table 1. Of the 15026 subjects at baseline, the mean age (SD) was 54.2 (5.8) years, and 6824 (45.4%) were men. The study cohort consists of 11127 (74.0%) White and 3899 (26.0%) Black and no other racial groups. A total of 3965 (41.2%) subjects were current smokers, 5255 (35.0%) had hypertension, and 1514 (10.1%) had diabetes. From visit 1 to visit 4, there was an increase of BMI, systolic blood pressure, prevalence of diabetes and hypertension, and use of calcium antagonist, digoxin, and β blocker; and a decline of diastolic blood pressure, total cholesterol, and prevalence of current smoking. The prevalence of high cardiovascular health was 11.2% at visit 1 and decreased gradually to 7.7% at visit 4. Subjects had a mean of 2.7 ideal metrics at baseline, keeping stably at 2.5 ideal metrics during the follow-up visits.

Association of Baseline and Time-Varying CVH With SCD/NSCD

After a median follow-up of 23.0 (interquartile range, 19.8–23.6) years from baseline, 583 SCD and 780 NSCD events occurred. A strong inverse association was observed between baseline CVH metrics with incidence of SCD. When CVH metrics were treated as time-varying variables, intermediate and ideal CVH status were associated with a 56% (HR, 0.44 [95%
CI, 0.35–0.55] and a 73% (HR, 0.27 [95% CI, 0.14–0.53]) reduction in risk of SCD, compared with poor CVH. Likewise, the risk of SCD decreased significantly and linearly with both increasing number of ideal metrics (HR, 0.69 [95% CI, 0.64–0.75] for per additional metric) and increasing global CVH metrics (HR, 0.79 [95% CI, 0.75–0.83] for 1-point increment) (Table 2). Similar patterns were found for NSCD. In the adjusted restricted cubic spline models, the risk of SCD and NSCD declined continually with increased CVH metrics across the range 0 to 14 scores (Figure 1). The incidence rates of SCD and NSCD by categories of

---

| Table 1. Characteristics of Subjects from Visit 1 to 4* |
|-------------------------------------------------------|
| Characteristic                                       | Visit 1 | Visit 2 | Visit 3 | Visit 4 |
|-------------------------------------------------------|
| No. of subjects                                      | 15 026  | 13 626  | 12 207  | 11 006  |
| Age, y                                                | 54.2 (5.8) | 57.1 (5.7) | 60.1 (5.7) | 62.9 (5.7) |
| Male sex, (%)                                         | 6824 (45.4) | 6165 (45.2) | 5483 (44.9) | 4924 (44.7) |
| White race, (%)                                       | 11 127 (74.1) | 10 383 (76.2) | 9517 (78.0) | 8632 (78.4) |
| Black race, (%)                                       | 3899 (25.9) | 3243 (23.8) | 2620 (22.0) | 2374 (21.8) |
| Education, %                                          | <High school 3558 (23.7) | 2952 (21.7) | 2452 (20.1) | 2093 (19.0) |
|                                                       | High school/vocational school 6159 (41.0) | 5689 (41.8) | 5123 (42.0) | 4659 (42.3) |
|                                                       | College, graduate, or professional school 5309 (35.3) | 4985 (36.6) | 4632 (38.0) | 4264 (38.7) |
| Income (US$), %                                       | <16000 3245 (21.6) | 2665 (19.6) | 2196 (18.0) | 1876 (17.1) |
|                                                       | 16000 to <25 000 2133 (14.2) | 1933 (14.2) | 1733 (14.2) | 1519 (13.8) |
|                                                       | 25 000 to <35 000 3389 (22.6) | 3131 (23.0) | 2783 (22.8) | 2566 (23.2) |
|                                                       | 35 000 to <50 000 2728 (18.2) | 2557 (18.8) | 2375 (19.5) | 2178 (19.8) |
|                                                       | ≥50 000 3531 (23.5) | 3340 (24.5) | 3120 (25.6) | 2877 (26.1) |
| Smoking status, %                                     | Never 3965 (26.4) | 5345 (39.2) | 5001 (41.0) | 4597 (41.8) |
|                                                       | Former 4858 (32.3) | 5179 (38.0) | 5030 (41.2) | 4776 (43.4) |
|                                                       | Current 3965 (41.2) | 3102 (22.8) | 2176 (17.8) | 1633 (14.8) |
| Hypertension, %                                       | 5255 (35.0) | 4913 (36.1) | 4996 (40.9) | 5240 (47.6) |
| Diabetes, %                                           | 1514 (10.1) | 1612 (11.8) | 1902 (15.6) | 1845 (16.8) |
| Body mass index, kg/m²                                 | 27.7 (5.4) | 28.0 (5.4) | 28.5 (5.6) | 28.8 (5.6) |
| Blood pressure, mmHg                                   | Systolic 121.4 (19.1) | 121.7 (18.9) | 124.7 (19.2) | 127.7 (19.2) |
|                                                       | Diastolic 73.7 (11.4) | 72.1 (10.4) | 71.7 (10.6) | 71.0 (10.4) |
| Fasting glucose, mg/dL                                | 109.2 (40.8) | 114.5 (44.3) | 111.6 (42.5) | 111.0 (36.0) |
| Total cholesterol, mg/dL                              | 215.1 (42.1) | 210.0 (39.6) | 207.7 (37.7) | 200.8 (37.0) |
| Medication, %                                         | Calcium antagonist 537 (3.6) | 1008 (7.4) | 1433 (11.7) | 1471 (13.4) |
|                                                       | Digoxin 245 (1.6) | 279 (2.1) | 293 (2.4) | 291 (2.6) |
|                                                       | Beta blocker 803 (5.3) | 797 (5.9) | 860 (7.1) | 1003 (9.1) |
|                                                       | Antiarrhythmics 117 (0.8) | 92 (0.7) | 75 (0.6) | 80 (0.7) |
|                                                       | Healthy diet scores 2.3 (1.0) | 2.3 (1.0) | 2.2 (1.0) | 2.2 (1.0) |
|                                                       | Physical activity, met min/wk 5.9 (6.6) | 6.1 (6.6) | 5.4 (5.9) | 5.5 (6.0) |
| CVH status, No. of ideal metrics                      | Low, 0–2 7165 (47.7) | 7022 (51.5) | 6237 (51.1) | 5932 (53.9) |
|                                                       | Intermediate, 3–4 6184 (41.2) | 5320 (39.3) | 4845 (39.7) | 4229 (38.4) |
|                                                       | High, 5–7 1677 (11.2) | 1284 (9.4) | 1125 (9.2) | 845 (7.7) |
|                                                       | No. of ideal metrics 2.7 (1.4) | 2.5 (1.4) | 2.5 (1.4) | 2.5 (1.4) |
|                                                       | 14-point CVH scores 8.0 (2.3) | 8.0 (2.3) | 7.9 (2.3) | 7.9 (2.2) |

CVH indicates cardiovascular health.  
*Values are mean (SD) unless indicated otherwise.
Zhai et al Change of CVH and SCD

CVH metrics, number of ideal metrics, and level of 14-point CVH score at baseline are presented in Table S2. Table S3 shows incidence rate and HRs of SCD and NSCD associated with baseline individual CVH metric components. For smoking, BMI, blood glucose, total cholesterol, and blood pressure, there was a graded decline in risk of SCD and NSCD from poor to intermediate/ideal CVH status. For physical activity, only ideal CVH status was associated with decreased risk of SCD and NSCD. Nevertheless, CVH status of diet did not seem to be related to these outcomes.

There was a steep gradient relationship between time-varying individual components of the CVH metrics with risk of SCD. Specially, we observed that ideal status of smoking, BMI, physical activity, blood glucose, and blood pressure were significantly associated with a lower risk of SCD. Similar results were found for the outcome of NSCD (Table S4).

**Table 2. Baseline and Time-Varying CVH Metrics and Risk of Sudden Cardiac Death and Nonsudden Cardiac Death**

| CVH status adjusted HR (95% CI)* | No. of ideal metrics | Per additional ideal metric | Per 1-point increase in the 14-point CVH score |
|---------------------------------|----------------------|----------------------------|-----------------------------------------------|
| **Baseline CVH**                |                      |                            |                                               |
| Poor health, 0–2                | 1.00 (ref.)          | 0.53 (0.44–0.64)           | 0.27 (0.16–0.45)                             |
| Intermediate health, 3–4       | 0.53 (0.45–0.62)     | 0.29 (0.19–0.44)           | 0.71 (0.67–0.75)                             |
| Ideal health, 5–7               | 0.72 (0.67–0.77)     | 0.78 (0.75–0.80)           |                                               |
| **Time-varying CVH**            |                      |                            |                                               |
| Poor health, 0–2                | 1.00 (ref.)          | 0.44 (0.35–0.55)           | 0.27 (0.14–0.53)                             |
| Intermediate health, 3–4       | 0.55 (0.45–0.67)     | 0.31 (0.18–0.55)           | 0.74 (0.69–0.79)                             |
| Ideal health, 5–7               | 0.69 (0.64–0.75)     | 0.79 (0.75–0.83)           |                                               |

CVH indicates cardiovascular health; and HR, hazard ratio.
*Adjustment for age, race, sex, education, income, history of coronary heart disease, and use of cardiovascular medications at baseline.

**Association of Change in CVH (1987–1989 to 1993–1995) With Subsequent SCD/NSCD**

Change in CVH metrics was examined between 1987 to 1989 and 1993 to 1995 over a median follow-up of 17.1 (interquartile range, 15.7–17.7) years in 12,207 subjects who had 7 metrics at both time points. Tables S5 and S6 shows the baseline characteristics of the subjects by patterns of change in CVH metrics and change in the level of individual CVH metrics between visit 1 and visit 3 was presented in Table S7.

After a median follow-up of 17.1 (interquartile range, 15.7–17.7) years after visit 3 (1993–1995), 372 SCD and 501 NSCD events occurred. The Kaplan–Meier curves in Figure 2 indicate a graded association across the 7 patterns of change for both SCD and NSCD. Compared with subjects with consistently poor overall CVH

**Figure 1.** Restricted cubic curve of hazards ratio for sudden cardiac death (A) and nonsudden cardiac death (B) against time-varying 14-point cardiovascular health scores.
*Adjustment for age, race, sex, education, income, history of coronary heart disease, and use of cardiovascular medications at baseline.
metrics at both visits, the risk of SCD was significantly decreased in those changed from poor to intermediate/ideal (HR, 0.67 [95% CI, 0.48–0.94]), intermediate to poor (HR, 0.73 [95% CI, 0.54–0.99]), intermediate to ideal (HR, 0.49 [95% CI, 0.24–0.99]), ideal to poor/intermediate CVH (HR, 0.23 [95% CI, 0.10–0.52]), or those with consistently intermediate (HR, 0.49 [95% CI, 0.36–0.66]) or consistently ideal CVH (HR, 0.31 [95% CI, 0.13–0.76]) (Table 3) (Figure S1).

Of note, in multivariable analysis adjusting for baseline number of ideal metrics and CVH score, the risk of SCD was lower in subjects who lost 1 or 2, had no change, gained 1 or 2, or gained ≥3 ideal metrics, as compared with those lost ≥3 ideal metrics. Likewise, there was a stepwise decrease in the risk of SCD across the patterns of change in 14-point CVH score. Accordingly, the adjusted HRs of SCD for per 1-unit of change in the number of ideal metrics and per 1-unit of change in the 14-point CVH score were 0.83 (95% CI, 0.73–0.95) and 0.83 (95% CI, 0.75–0.91), respectively. Similar results were also observed for NSCD (Table 3).

Table 4 shows the HRs of SCD and NSCD associated with changes in 7 individual CVH metric components. Compared with subjects with consistently poor change, gained 1 or 2, or gained ≥3 ideal metrics, as compared with those lost ≥3 ideal metrics. Likewise, there was a stepwise decrease in the risk of SCD across the patterns of change in 14-point CVH score. Accordingly, the adjusted HRs of SCD for per 1-unit of change in the number of ideal metrics and per 1-unit of change in the 14-point CVH score were 0.83 (95% CI, 0.73–0.95) and 0.83 (95% CI, 0.75–0.91), respectively. Similar results were also observed for NSCD (Table 3).

Table 4 shows the HRs of SCD and NSCD associated with changes in 7 individual CVH metric components. Compared with subjects with consistently poor
Table 3. Change in CVH Status Between 1987 to 1989 and 1993 to 1995, and Association With Sudden Cardiac Death and Nonsudden Cardiac Death

| Change in CVH status * | Sudden cardiac death | Nonsudden cardiac death |
|------------------------|----------------------|-------------------------|
|                        | Events/subjects | Incidence rate per 1000 person-years (95% CI) | Adjusted HR (95% CI) | Events/subjects | Incidence rate per 1000 person-years (95% CI) | Adjusted HR (95% CI) |
| Consistently poor      | 202/4225        | 3.3 (2.9–3.8)            | 1.00 (ref.)           | 271/4225        | 4.4 (3.9–5.0)            | 1.00 (ref.)           |
| Poor to intermediate/ideal | 41/1261      | 2.2 (1.6–3.0)            | 0.67 (0.48–0.94)      | 59/1261         | 3.1 (2.4–4.1)            | 0.71 (0.54–0.94)      |
| Intermediate to poor   | 55/1873         | 1.9 (1.5–2.5)            | 0.73 (0.54–0.99)      | 64/1873         | 2.2 (1.7–2.8)            | 0.61 (0.46–0.80)      |
| Consistently intermediate | 55/2912      | 1.2 (0.9–1.6)            | 0.49 (0.36–0.66)      | 74/2912         | 1.6 (1.3–2.0)            | 0.45 (0.34–0.58)      |
| Intermediate to ideal  | 8/435           | 1.2 (0.6–2.3)            | 0.49 (0.24–0.99)      | 12/435          | 1.8 (1.0–3.1)            | 0.49 (0.27–0.87)      |
| Ideal to poor/intermediate | 6/871       | 0.4 (0.2–0.9)            | 0.23 (0.10–0.52)      | 14/871          | 1.0 (0.6–1.7)            | 0.35 (0.20–0.60)      |
| Consistently ideal     | 6/630           | 0.5 (0.2–1.2)            | 0.31 (0.13–0.76)      | 7/630           | 0.7 (0.3–1.4)            | 0.27 (0.13–0.58)      |

| Change in no. of ideal metrics † |  |  |  |  |  |  |
|----------------------------------|  |  |  |  |  |  |
|                                  |  |  |  |  |  |  |
| Per 1 additional ideal metric    | 0.83 (0.73–0.95) | 0.89 (0.79–1.00) |
| Lost ≥3 ideal metrics            | 13/373         | 2.2 (1.3–3.8)            | 1.00 (ref.)           | 9/373           | 1.5 (0.8–2.9)            | 1.00 (ref.)           |
| Lost 1 or 2 ideal metrics        | 119/4442       | 1.7 (1.5–2.1)            | 0.39 (0.22–0.70)      | 164/4442        | 2.4 (2.1–2.8)            | 0.85 (0.43–1.68)      |
| No change in ideal metrics       | 134/4267       | 2.1 (1.7–2.5)            | 0.33 (0.18–0.61)      | 167/4267        | 2.6 (2.2–3.0)            | 0.64 (0.32–1.28)      |
| Gained 1 or 2 ideal metrics      | 101/2973       | 2.3 (1.9–2.7)            | 0.29 (0.16–0.55)      | 155/2973        | 3.5 (3.0–4.1)            | 0.69 (0.34–1.39)      |
| Gained ≥3 ideal metrics          | 5/152          | 2.2 (0.9–5.1)            | 0.26 (0.09–0.77)      | 6/152           | 2.6 (1.2–5.7)            | 0.44 (0.15–1.29)      |

| Change in 14-point CVH score ‡ |  |  |  |  |  |  |
|---------------------------------|  |  |  |  |  |  |
|                                  |  |  |  |  |  |  |
| Per 1-point increase in score   | 0.83 (0.75–0.91) | 0.88 (0.81–0.96) |
| Lost ≥3 points                   | 41/1415        | 1.9 (1.4–2.6)            | 1.00 (ref.)           | 48/1415         | 2.2 (1.7–2.9)            | 1.00 (ref.)           |
| Lost 1 or 2 points               | 118/4111       | 1.9 (1.6–2.3)            | 0.76 (0.53–1.08)      | 148/4111        | 2.4 (2.0–2.8)            | 0.84 (0.60–1.16)      |
| No change in score               | 72/2726        | 1.7 (1.4–2.2)            | 0.54 (0.36–0.80)      | 113/2726        | 2.7 (2.3–3.3)            | 0.74 (0.52–1.04)      |
| Gained 1 or 2 points             | 105/3109       | 2.2 (1.8–2.7)            | 0.53 (0.36–0.78)      | 141/3109        | 3.0 (2.5–3.5)            | 0.65 (0.46–0.92)      |
| Gained ≥3 points                 | 36/846         | 2.9 (2.1–4.0)            | 0.46 (0.26–0.75)      | 51/846          | 4.1 (3.1–5.4)            | 0.61 (0.40–0.94)      |

CVH indicates cardiovascular health; and HR, hazard ratio.
*Adjustment for age, race, sex, education, income, history of coronary heart disease, and use of cardiovascular medications at baseline.
†Further adjustment for number of ideal metrics and CVH score at baseline.
Table 4. Association of Change in Individual Cardiovascular Health Metrics Between 1987 to 1989 and 1993 to 1995 With Sudden Cardiac Death and Nonsudden Cardiac Death

|                  | Sudden cardiac death | Nonsudden cardiac death |
|------------------|----------------------|-------------------------|
|                  | Events/subjects | Incidence rate per 1000 person-years (95% CI) | Adjusted HR (95% CI)* | Events/subjects | Incidence rate per 1000 person-years (95% CI) | Adjusted HR (95% CI)* |
| **Smoking**       |                   |                         |                       |                   |                         |                       |
| Consistently poor | 83/1977            | 3.0 (2.4–3.7)           | 1.00 (ref.)           | 93/1977           | 3.3 (2.7–4.1)           | 1.00 (ref.)           |
| Poor to intermediate/ideal | 37/841          | 3.1 (2.2–4.2)           | 0.99 (0.67–1.46)     | 54/841           | 4.5 (3.4–5.8)           | 1.23 (0.88–1.73)     |
| Intermediate to poor | 9/170            | 3.7 (1.9–6.9)           | 1.10 (0.55–2.19)     | 14/170           | 5.7 (5.4–9.5)           | 1.53 (0.87–2.70)     |
| Consistently intermediate | 118/3786      | 2.0 (1.7–2.4)           | 0.61 (0.46–0.81)     | 173/3876          | 3.0 (2.6–3.5)           | 0.73 (0.56–0.95)     |
| Intermediate to ideal | 4/140             | 1.9 (0.7–4.8)           | 0.47 (0.17–1.29)     | 3/140             | 1.4 (0.5–4.1)           | 0.28 (0.09–0.88)     |
| Ideal to poor/intermediate | 19/484         | 2.5 (1.6–3.9)           | 0.79 (0.48–1.31)     | 20/484           | 2.6 (1.7–4.1)           | 0.71 (0.44–1.16)     |
| Consistently ideal | 102/4809          | 1.4 (1.1–1.6)           | 0.51 (0.38–0.68)     | 144/4809          | 1.9 (1.6–2.2)           | 0.53 (0.40–0.69)     |
| **Body mass index** |                   |                         |                       |                   |                         |                       |
| Consistently poor | 131/2961          | 3.0 (2.5–3.5)           | 1.00 (ref.)           | 161/2961          | 3.6 (3.1–4.2)           | 1.00 (ref.)           |
| Poor to intermediate/ideal | 12/281          | 3.1 (1.8–5.5)           | 0.84 (0.46–1.52)     | 20/281           | 5.2 (3.4–8.1)           | 1.14 (0.72–1.82)     |
| Intermediate to poor | 20/1055          | 1.2 (0.8–1.9)           | 0.45 (0.28–0.72)     | 37/1055           | 2.3 (1.7–3.1)           | 0.66 (0.46–0.94)     |
| Consistently intermediate | 105/3453      | 2.0 (1.6–2.4)           | 0.62 (0.47–0.80)     | 148/3453          | 2.8 (2.4–3.3)           | 0.69 (0.55–0.87)     |
| Intermediate to ideal | 21/384           | 3.9 (2.6–5.9)           | 1.13 (0.71–1.70)     | 28/384           | 5.2 (3.6–7.5)           | 1.19 (0.79–1.78)     |
| Ideal to poor/intermediate | 24/1115         | 1.4 (0.9–2.0)           | 0.61 (0.39–0.94)     | 23/1115           | 1.3 (0.9–2.0)           | 0.43 (0.28–0.66)     |
| Consistently ideal | 59/2958           | 1.3 (1.0–1.7)           | 0.52 (0.38–0.71)     | 84/2958           | 1.9 (1.5–2.3)           | 0.55 (0.42–0.72)     |
| **Diet**          |                   |                         |                       |                   |                         |                       |
| Consistently poor | 43/1036           | 2.8 (2.0–3.7)           | 1.00 (ref.)           | 47/1036           | 3.0 (2.3–4.0)           | 1.00 (ref.)           |
| Poor to intermediate/ideal | 42/1447          | 1.9 (1.4–2.6)           | 0.73 (0.48–1.12)     | 63/1447           | 2.9 (2.3–3.7)           | 0.95 (0.65+–1.39)    |
| Intermediate to poor | 58/1428          | 2.7 (2.1–3.5)           | 0.99 (0.67–1.48)     | 66/1428           | 3.1 (2.4–3.9)           | 1.00 (0.68–1.45)     |
| Consistently intermediate | 174/6324      | 1.8 (1.5–2.1)           | 0.80 (0.57–1.13)     | 231/6324          | 2.4 (2.1–2.7)           | 0.85 (0.62–1.17)     |
| Intermediate to ideal | 27/766           | 2.3 (1.6–3.3)           | 0.97 (0.60–1.59)     | 40/766            | 3.4 (2.5–4.6)           | 1.15 (0.75–1.76)     |
| Ideal to poor/intermediate | 23/906          | 1.7 (1.1–2.5)           | 0.76 (0.46–1.28)     | 39/906           | 2.8 (2.1–3.9)           | 0.97 (0.63–1.50)     |
| Consistently ideal | 5/300             | 1.1 (0.5–2.5)           | 0.47 (0.18–1.19)     | 15/300           | 3.2 (2.0–5.3)           | 1.08 (0.60–1.94)     |
| **Physical activity** |                   |                         |                       |                   |                         |                       |
| Consistently poor | 99/2620           | 2.6 (2.1–3.1)           | 1.00 (ref.)           | 135/2620          | 3.5 (3.0–4.2)           | 1.00 (ref.)           |
| Poor to intermediate/ideal | 57/1753          | 2.2 (1.7–2.8)           | 0.83 (0.60–1.15)     | 72/1753           | 2.7 (2.2–3.4)           | 0.72 (0.54–0.96)     |
| Intermediate to poor | 11/367            | 2.0 (1.1–3.5)           | 0.94 (0.50–1.76)     | 19/367           | 3.4 (2.2–5.3)           | 1.12 (0.69–1.81)     |
| Consistently intermediate | 4/137             | 1.9 (0.7–4.9)           | 1.02 (0.37–2.77)     | 5/137             | 2.4 (1.0–5.6)           | 0.81 (0.33–1.97)     |
| Intermediate to ideal | 9/481              | 1.2 (0.6–2.3)           | 0.55 (0.28–1.09)     | 25/481           | 3.4 (2.3–5.0)           | 1.00 (0.65–1.54)     |

(Continued)
### Table 4. Continued

|                              | Sudden cardiac death | Non-sudden cardiac death |
|------------------------------|----------------------|--------------------------|
|                              | Events/subjects | Incidence rate per 1000 person-years (95% CI) | Adjusted HR (95% CI)* | Events/subjects | Incidence rate per 1000 person-years (95% CI) | Adjusted HR (95% CI)* |
| Ideal to poor/intermediate   | 80/2115         | 2.5 (2.0–3.1)             | 1.10 (0.82–1.48)       | 78/2115         | 2.4 (2.0–3.0)             | 0.72 (0.54–0.96)       |
| Consistently ideal           | 112/4734        | 1.5 (1.3–1.8)             | 0.72 (0.54–0.95)       | 167/4734        | 2.3 (2.0–2.6)             | 0.68 (0.54–0.87)       |

#### Blood glucose

|                              | Incidence rate per 1000 person-years (95% CI) | Adjusted HR (95% CI)* | Incidence rate per 1000 person-years (95% CI) | Adjusted HR (95% CI)* |
|------------------------------|---------------------------------------------|------------------------|---------------------------------------------|------------------------|
| Consistently poor            | 6.4 (5.1–8.1)                               | 1.00 (ref.)            | 6.5 (5.1–8.2)                               | 1.00 (ref.)            |
| Poor to intermediate/ideal   | 4.6 (2.7–7.8)                               | 0.72 (0.40–1.31)       | 6.6 (4.3–10.4)                              | 0.99 (0.60–1.65)       |
| Intermediate to poor         | 4.1 (3.0–2.6)                               | 0.76 (0.52–1.12)       | 5.5 (4.2–7.2)                               | 1.02 (0.72–1.46)       |
| Consistently intermediate    | 1.8 (1.5–2.3)                               | 0.35 (0.25–0.48)       | 3.0 (1.6–5.5)                               | 0.92 (0.58–1.47)       |
| Intermediate to ideal        | 1.7 (1.2–2.3)                               | 0.31 (0.21–0.48)       | 2.7 (2.1–3.5)                               | 0.47 (0.33–0.67)       |
| Ideal to poor/intermediate   | 1.6 (1.2–2.1)                               | 0.34 (0.23–0.49)       | 2.7 (2.2–3.4)                               | 0.55 (0.39–0.75)       |
| Consistently ideal           | 1.3 (1.1–1.6)                               | 0.31 (0.23–0.43)       | 1.7 (1.4–2.0)                               | 0.37 (0.27–0.50)       |

#### Total cholesterol

|                              | Incidence rate per 1000 person-years (95% CI) | Adjusted HR (95% CI)* | Incidence rate per 1000 person-years (95% CI) | Adjusted HR (95% CI)* |
|------------------------------|---------------------------------------------|------------------------|---------------------------------------------|------------------------|
| Consistently poor            | 2.2 (1.6–2.8)                               | 1.00 (ref.)            | 3.1 (2.4–4.0)                               | 1.00 (ref.)            |
| Poor to intermediate/ideal   | 3.1 (2.4–3.9)                               | 1.26 (0.87–1.84)       | 4.3 (3.5–5.2)                               | 1.31 (0.95–1.80)       |
| Intermediate to poor         | 1.6 (1.0–2.6)                               | 0.89 (0.51–1.65)       | 2.3 (1.6–3.4)                               | 0.92 (0.58–1.47)       |
| Consistently intermediate    | 1.7 (1.4–2.3)                               | 0.80 (0.55–1.16)       | 2.7 (2.2–3.7)                               | 0.90 (0.66–1.23)       |
| Intermediate to ideal        | 2.5 (1.9–3.3)                               | 1.06 (0.71–1.58)       | 2.9 (2.3–3.7)                               | 0.94 (0.66–1.34)       |
| Ideal to poor/intermediate   | 1.9 (1.3–2.6)                               | 1.06 (0.68–1.66)       | 2.2 (1.6–2.9)                               | 0.92 (0.62–1.37)       |
| Consistently ideal           | 1.6 (1.3–2.0)                               | 0.70 (0.48–1.01)       | 2.0 (1.7–2.4)                               | 0.71 (0.52–0.98)       |

#### Blood pressure

|                              | Incidence rate per 1000 person-years (95% CI) | Adjusted HR (95% CI)* | Incidence rate per 1000 person-years (95% CI) | Adjusted HR (95% CI)* |
|------------------------------|---------------------------------------------|------------------------|---------------------------------------------|------------------------|
| Consistently poor            | 5.0 (4.0–6.3)                               | 1.00 (ref.)            | 5.6 (4.5–7.0)                               | 1.00 (ref.)            |
| Poor to intermediate/ideal   | 4.5 (3.5–5.8)                               | 1.00 (0.70–1.41)       | 5.2 (4.1–6.7)                               | 1.10 (0.79–1.52)       |
| Intermediate to poor         | 2.6 (2.0–3.5)                               | 0.58 (0.40–0.84)       | 4.2 (3.3–5.3)                               | 0.79 (0.57–1.08)       |
| Consistently intermediate    | 1.9 (1.6–2.4)                               | 0.47 (0.34–0.64)       | 3.0 (2.5–3.5)                               | 0.62 (0.47–0.82)       |
| Intermediate to ideal        | 1.8 (1.1–2.8)                               | 0.47 (0.28–0.80)       | 2.6 (1.8–3.8)                               | 0.61 (0.38–0.96)       |
| Ideal to poor/intermediate   | 1.3 (1.0–1.5)                               | 0.39 (0.26–0.58)       | 2.0 (1.6–2.6)                               | 0.51 (0.37–0.72)       |
| Consistently ideal           | 1.0 (0.7–1.3)                               | 0.33 (0.23–0.48)       | 1.1 (0.9–1.4)                               | 0.33 (0.24–0.47)       |

HR indicates hazard ratio.

*Adjustment for age, race, sex, education, income, history of coronary heart disease, and use of cardiovascular medications at baseline.
CVH, those with ideal CVH at baseline, regardless of whether there was a decline in CVH, or those with consistently intermediate CVH experienced lower risk of SCD for smoking, BMI, blood glucose, and blood pressure. However, for diet and total cholesterol, any change category did not seem to significantly reduce the risk. For physical activity, only persistent ideal CVH status was associated with decreased risk. In addition, no significant difference was observed in SCD risk for the poor to intermediate/ideal transition for each CVH metric. The results were similar for NSCD, albeit the risk magnitude seems to be greater than SCD.

Sensitivity
In the sensitivity analysis of adjusting for competing risk, the results were consistent with the main findings (Table S8). We performed further stratified analyses by sex and race. The risk of SCD did not differ significantly between men and women or White people and Black people (Tables S9 and S10).

DISCUSSION
In this prospective community-based, biracial cohort of middle-aged individuals in the United States, we reported 3 key findings: (1) compared with poor CVH status, baseline and time-variying intermediate and ideal measures of CVH were inversely associated with risk of SCD and NSCD; (2) the risk of SCD was significantly lower in subjects who changed from poor to intermediate/ideal, intermediate to poor, intermediate to ideal, ideal to poor/intermediate CVH, or those with persistently intermediate or ideal CVH, when compared with stable poor CVH metrics; and (3) a strong gradient relationship was observed between the direction of change in category of CVH metrics and risk of SCD. These findings highlight the importance of promotion of ideal CVH in the primordial prevention of SCD.

Prior reports have demonstrated associations between change of CVH metrics over time and occurrence of subclinical or clinical outcomes. The Framingham Offspring Study has reported that participants who remained in poor CVH or changed from poor to ideal or ideal to poor CVH experienced higher incidence of cardiovascular disease and death as compared with those maintained ideal CVH over 20 years. More time spent in intermediate or ideal CVH in midlife is potentially cardiometabolic beneficial and might be related to a lower risk of death in later life. However, in the United Kingdom’s Whitehall II study that examined patterns of CVH change with cardiovascular events, the authors reported that improving CVH from poor to intermediate or poor to ideal did not seem to be associated with reduction in subsequent risk of cardiovascular disease and death.

Compared with persistent poor CVH, other categories of change in global CVH metrics were related to lower risk of SCD. However, there seem to be no consistent association between the direction of change in individual CVH and the outcomes. Four of 7 metrics, including smoking, BMI, blood glucose, and blood pressure, demonstrated decreased risk in subjects with ideal CVH at baseline or consistently intermediate CVH. It might not be surprising, because previous reports have identified these components to be independent risk factors for SCD. For example, hypertension is a leading cause for left ventricular hypertrophy, coronary heart disease, heart failure, and electrophysiological abnormalities of ventricles, which would in turn lead to the occurrence of SCD. However, changes of diet and total cholesterol were not significantly related to SCD. The reasons for these findings were not clear. Notably, Isicoroz et al. also found no significant relationship between both ideal diet and total cholesterol at baseline and subsequent risk of SCD. We postulated that follow-up time in our study might not be long enough to discern the effects of diet and total cholesterol. It is possible that longer time was required to cause cardiac change associated with SCD for both risk factors. There is also the possibility that the relationship between diet or total cholesterol per se and SCD is relatively weak. The discrepancy between global CVH and individual CVH indicates that more attention should be focused on the change of CVH as a whole for primordial prevention of SCD, whereas promoting change in a single cardiovascular risk factor might be of limited value in preventing SCD.

Our results have several important public health implications. First, nearly half of the entire population had poor CVH at baseline, approximately one-third remained at poor CVH, and only a small proportion improved their CVH status over 6 years. Our data indicate, however, that promotion of CVH from poor to intermediate/ideal could lead to substantial benefits even in midlife. Therefore, more aggressive efforts are warranted to target a younger population and to shift more people with poor CVH in this age group toward ideal CVH. Second, subjects worsening from intermediate or ideal CVH to lower CVH status still had decreased risk of SCD. We speculate that initial attainment of intermediate or ideal CVH could have blunted some of the risk related to the future worsening in CVH. Third, our findings demonstrated that, overall, the risk of SCD was 71% lower for those gaining 1 or 2 ideal metrics, and 74% lower for those gaining ≥3 ideal metrics compared with subjects losing ≥3 ideal metrics. There were linearly incremental beneficial effects corresponding to the increases of number of ideal CVH, which corroborated the potential of targeting multiple lifestyle factors simultaneously with community-based strategies to reduce the incidence of SCD worldwide.
Fourth, improvement in CVH metrics in the general population might require multipronged approaches and policy initiatives, including efforts from individuals, health professionals, researchers, and policy makers to influence public health.

Strengths of our study include a large community-based sample, multiple examinations, biracial and bimodal population, over 2 decades of follow-up, and systematic diagnosis of SCD cases with validation by an independent panel of physicians. However, several limitations also deserve mention. First, similar to other large prospective cohort studies, diet and physical activity levels in the current study were self-reported, which might be subject to misclassification bias. Second, although we adjusted for multiple confounding factors, there is the possibility that residual confounding by unmeasured covariates still exists. For example, given the limited data available, we could not adjust for baseline ejection fraction, which is a well-established marker of SCD. Third, the observational design precludes causal inferences, which called for large well-designed randomized control trials to confirm these findings. Fourth, changes in the CVH metrics across repeated examinations could also be influenced by cohort attrition, aging, and temporal trends.

Conclusions
In conclusion, our investigation of this community-based cohort study demonstrated that baseline, time-varying, and change in CVH were associated with risk of SCD and NSCD. These findings highlight the importance of promotion of, and adherence to, moderate to high CVH to prevent risk factors associated with SCD.

ARTICLE INFORMATION
Received July 4, 2022; accepted September 6, 2022.

Affiliations
Department of Cardiology (Y.-S.G., W.-T.B., L.-p.Q., Y.-J.C.) and Department of Obstetrics and Gynecology (Z.-Y.L.), The First Affiliated Hospital, Sun Yat-Sen University, Guangzhou, China; Key Laboratory on Assisted Circulation, Ministry of Health, Guangzhou, China (Y.-S.Z., W.-T.B., L.-p.Q., Y.-J.C.); Department of Cardiovascular Medicine, People’s Hospital of Macheng City, Macheng City, China (W.-B.T.); Cardiac Arrhythmia Center, State Key Laboratory of Cardiovascular Disease, Fuwai Hospital, National Center for Cardiovascular Diseases, Chinese Academy of Medical Sciences and Peking Union Medical College, Beijing, People’s Republic of China (Y.-H.J.); and Department of Cardiology, Guangdong Cardiovascular Institute, Guangdong Provincial People’s Hospital, Guangdong Academy of Medical Sciences, Guangzhou, China (Y-J.C.).

Acknowledgments
The authors thank the staff and participants of the ARC study and Biologic Specimen and Data Repository Information Coordinating Center for their important contributions.

Sources of Funding
The study was also financially supported by the grants from National Natural Science Foundation of China (81600260, 82270333, Guangdong Basic and Applied Basic Research Foundation (2021A1515010405), the project of Guangdong Province Science and Technology Plan (2017A020215174), Sun Yat-sen University Training Project Foundation for Young Teachers (19yky183), the project of Kelyn new star of the First Affiliated Hospital of Sun Yat-Sen University (Y50186), and the clinical research plan of the Eastern Hospital of the First Affiliated Hospital of Sun Yat-Sen University (2019007).

Disclosures
The authors declare no potential conflict of interest.

Supplemental Material
Tables S1–S10
Figure S1

REFERENCES
1. Virani SS, Alonso A, Aparicio HJ, Benjamin EJ, Bittencourt MS, Callaway CW, Carson AP, Chamberlain AM, Cheng S, Delling FN, et al. Heart disease and stroke statistics-2021 update: a report from the American Heart Association. Circulation. 2021;143:e259–e743. doi: 10.1161/CIR.0000000000000950
2. Kusumoto FM, Bailey KR, Chauki AS, Deshmukh AJ, Gautam S, Kim RJ, Kramer DB, Lambrakos LK, Nasser NH, Sorajja D. Systematic review for the 2017 AHA/ACC/HRS guideline for management of patients with ventricular arrhythmias and the prevention of sudden cardiac death: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines and the Heart Rhythm Society. Circulation. 2018;138:e392–e414. doi: 10.1161/CIR.0000000000005550
3. Stecker EC, Vickers C, Waltz J, Socoteanu C, John BT, Mariani R, McNulty JH, Gunson K, Jui J, Chugh SS. Population-based analysis of sudden cardiac death with and without left ventricular systolic dysfunction: two-year findings from the Oregon Sudden Unexpected Death Study. J Am Coll Cardiol. 2006;47:1161–1166. doi: 10.1016/j.jacc.2005.11.045
4. Pan H, Hibino M, Kobiesi E, Aune D. Blood pressure, hypertension and the risk of sudden cardiac death: a systematic review and meta-analysis of cohort studies. Eur J Epidemiol. 2020;35:443–454. doi: 10.1007/s10654-019-00593-4
5. Lyne TH, Svane J, Pedersen-Bjergaard U, Gislason G, Torp-Pedersen C, Banner J, Riegard B, Winkel BG, Tfelt-Hansen J. Sudden cardiac death among persons with diabetes aged 1-49 years: a 10-year nationwide study of 124 deaths in Denmark. Eur Heart J. 2020;41:2699–2706. doi: 10.1093/eurheartj/ehz1891
6. Aune D, Schlesinger S, Harner M, Norat T, Riboli E. Physical activity and the risk of sudden cardiac death: a systematic review and meta-analysis of prospective studies. BMC Cardiovasc Disord. 2020;20:318. doi: 10.1186/s12872-020-01531-z
7. Hagnas MJ, Lakka TA, Makikallio TH, Kurl S, Savonen K, Aurumajarvi R, Laukkanen JA. High leisure-time physical activity is associated with reduced risk of sudden cardiac death among men with low cardiorespiratory fitness. Can J Cardiol. 2018;34:288–294. doi: 10.1016/j.jcc.2017.12.003
8. Shikany JM, Safford MM, Soroka O, Brown TM, Newby PK, Durant RW, Judd SE. Mediterranean diet Score, dietary patterns, and risk of sudden cardiac death in the REGARDS study. J Am Heart Assoc. 2021;10:e19158. doi: 10.1161/JAHA.120.019158
9. Goff DJ, Khan SS, Lloyd-Jones DM, Amett DK, Camenotthun MR, Labarthe DR, Loop MS, Luepker RV, McConnell MV, Mensah GA, et al. Bending the curve in cardiovascular disease mortality: Bethesda + 40 and beyond. Circulation. 2021;143:837–851. doi: 10.1161/CIRCULATIONAHA.120.046501
10. Lloyd-Jones DM, Hong Y, Labarthe D, Mozaffarian D, Appel LJ, Van Horn L, Greenland K, Daniels S, Nichol G, Tomasselli GF, et al. 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;121:686–693. doi: 10.1161/CIRCULATIONAHA.109.192703
11. Bundy JD, Zhu Z, Ning H, Zhong VW, Paluch AE, Willkins JT, Lloyd-Jones DM, Whelton PK, He J, Allen NB. Estimated impact of achieving optimal cardiovascular health among US adults on cardiovascular disease events. J Am Heart Assoc. 2021;10:e19681. doi: 10.1161/circ.141.suppt_1.35
| CVH metrics       | Poor                        | Intermediate                                      | Ideal                                             |
|-------------------|-----------------------------|---------------------------------------------------|--------------------------------------------------|
| Smoking           | Current smoker              | Quit smoking ≤12 months ago                       | Never smoked OR quit >12 months ago               |
| Body mass index   | ≥30 kg/m²                   | 25 to 29.9 kg/m²                                  | <25 kg/m²                                        |
| Healthy diet score*| 0-1 component               | 2-3 components                                    | 4-5 components                                   |
| Physical activity | No moderate or vigorous activity | 1-149 min/week moderate OR 1-74 min/week vigorous activity OR 1-149 min/week of moderate and vigorous activity | ≥150 min/week moderate activity OR ≥75 min/week vigorous activity OR ≥150 min/week moderate and vigorous activity |
| Fasting blood glucose | ≥126 mg/dL                  | 100–125 mg/dL OR <100 mg/dL treated              | <100 mg/dL untreated                             |
| Fasting total cholesterol | ≥240 mg/dL                 | 200–239 mg/dL OR <200 mg/dL treated              | <200 mg/dL untreated                             |
| Blood pressure (SBP/DBP) | SBP ≥140 OR DBP≥90 mmHg      | 120–139/80–89 mmHg OR <120/80 mmHg untreated      |                                                  |

CVH, cardiovascular health; SBP, systolic blood pressure; DBP, diastolic blood pressure.

*Diet was assessed using the 66-item Harvard food frequency questionnaire. Persons with extreme energy intake of <600 or >4,200 kcal/day for men or <500 or >3,600 kcal/day for women (approximate lower and upper 1 per-centiles) were excluded. The following 5 components were used to designate an ideal diet: fruits and vegetables: ≥4.5 cups per day; fish: ≥ two 3.5-oz servings per week; fiber-rich whole grains: ≥three 1-oz-equivalent servings per day; sodium: <1500 mg per day; sugar sweetened beverages: ≤450 kcal (36 oz) per week.
| CVH status, No. of ideal metrics | Sudden Cardiac Death | Non-sudden Cardiac Death |
|----------------------------------|----------------------|--------------------------|
| Poor, 0-2                        | 3.0 (2.7-3.3)        | 4.0 (3.6-4.3)            |
| Intermediate, 3-4                | 1.2 (1.0-1.4)        | 1.7 (1.5-1.9)            |
| Ideal, 5-7                       | 0.4 (0.2-0.7)        | 0.7 (0.4-1.0)            |
| CVH status per No. of ideal metrics |                      |                          |
| 0                                | 5.3 (4.1-6.7)        | 7.0 (5.6-8.6)            |
| 1                                | 3.3 (2.8-3.8)        | 4.7 (4.1-5.4)            |
| 2                                | 2.4 (2.1-2.8)        | 2.9 (2.6-3.3)            |
| 3                                | 1.6 (1.3-1.9)        | 2.0 (1.7-2.4)            |
| 4                                | 0.7 (0.5-1.0)        | 1.2 (0.9-1.5)            |
| 5                                | 0.5 (0.3-0.8)        | 0.7 (0.4-1.1)            |
| 6                                | 0.3 (0-1.0)          | 0.5 (0.1-1.4)            |
| 7                                | 0 (0-0.6)            | 0 (0-0.6)                |
| CVH status per points on the 14-point CVH score† | | |
| 1 or 2                           | 9.9 (5.7-16.0)       | 15.5 (10.0-22.7)         |
| 3 or 4                           | 5.2 (4.1-6.4)        | 6.5 (5.3-7.9)            |
| 5 or 6                           | 3.5 (3.0-4.0)        | 4.3 (3.8-4.9)            |
| 7 or 8                           | 1.9 (1.7-2.3)        | 2.8 (2.5-3.2)            |
| 9 or 10                          | 1.1 (0.8-1.3)        | 1.3 (1.1-1.6)            |
| 11 or 12                         | 0.5 (0.3-0.7)        | 0.8 (0.5-1.1)            |
| 13 or 14                         | 0 (0-0.6)            | 0.6 (0.2-1.6)            |

CVH, cardiovascular health.

*Incidence rates were calculated as events per 1000 person-years (95% confidence interval).

†The continuous 14-point CVH score was calculated by assigning 0 (poor), 1 (intermediate), and 2 (ideal) points to each of the 7 metrics and summing them.
Table S3. Association of baseline individual CVH metrics with incidence of sudden cardiac death and non-sudden cardiac death

|                  | Sudden Cardiac Death | Non-sudden Cardiac Death |
|------------------|-----------------------|--------------------------|
|                  | Incidence rates (95% CI) | HR* (95% CI) | Incidence rates (95% CI) | HR* (95% CI) |
| **Smoking†**     |                       |                         |                          |               |
| Poor             | 2.9 (2.5-3.3)         | 1.00                    | 3.7 (3.2-4.1)            | 1.00          |
| Intermediate     | 1.9 (1.6-2.1)         | 0.59 (0.48-0.72)        | 2.7 (2.4-3.1)            | 0.64 (0.54-1.77) |
| Ideal            | 1.4 (1.2-1.6)         | 0.56 (0.46-0.69)        | 1.8 (1.6-2.1)            | 0.49 (0.41-0.59) |
| **Body mass index†** |                       |                         |                          |               |
| Poor             | 2.8 (2.4-3.2)         | 1.00                    | 3.6 (3.2-4.1)            | 1.00          |
| Intermediate     | 1.9 (1.6-2.1)         | 0.66 (0.54-0.80)        | 2.6 (2.3-2.9)            | 0.68 (0.58-0.81) |
| Ideal            | 1.3 (1.1-1.5)         | 0.57 (0.46-0.71)        | 1.7 (1.5-2.0)            | 0.55 (0.45-0.66) |
| **Diet†**        |                       |                         |                          |               |
| Poor             | 2.1 (1.8-2.5)         | 1.00                    | 2.9 (2.5-3.4)            | 1.00          |
| Intermediate     | 2.0 (1.7-2.2)         | 1.04 (0.85-1.26)        | 2.5 (2.3-2.7)            | 0.90 (0.76-1.06) |
| Ideal            | 1.3 (0.9-1.7)         | 0.71 (0.49-1.03)        | 2.6 (2.0-3.2)            | 0.93 (0.71-1.23) |
| **Physical activity†** |                       |                         |                          |               |
| Poor             | 2.5 (2.2-2.8)         | 1.00                    | 2.9 (2.5-3.4)            | 1.00          |
| Intermediate     | 1.6 (1.1-2.2)         | 0.78 (0.56-1.10)        | 2.5 (2.3-2.7)            | 1.05 (0.81-1.37) |
| Ideal            | 1.6 (1.4-1.8)         | 0.78 (0.65-0.93)        | 2.6 (2.0-3.2)            | 0.78 (0.67-0.91) |
| **Blood glucose†** |                       |                         |                          |               |
| Poor             | 5.7 (4.8-6.7)         | 1.00                    | 7.9 (6.8-9.0)            | 1.00          |
| Intermediate     | 2.0 (1.8-2.3)         | 0.43 (0.35-0.54)        | 2.5 (2.2-2.8)            | 0.38 (0.31-0.45) |
| Ideal            | 1.2 (1.1-1.4)         | 0.32 (0.25-0.40)        | 1.7 (1.5-2.0)            | 0.31 (0.26-0.37) |
| **Total cholestero†** |                       |                         |                          |               |
| Poor             | 2.6 (2.2-3.0)         | 1.00                    | 3.4 (3.0-3.8)            | 1.00          |
| Intermediate     | 1.8 (1.6-2.1)         | 0.75 (0.62-0.92)        | 2.7 (2.4-3.0)            | 0.87 (0.73-1.03) |
| Ideal            | 1.6 (1.3-1.8)         | 0.65 (0.52-0.80)        | 1.9 (1.6-2.2)            | 0.66 (0.54-0.79) |
| **Blood pressure†** |                       |                         |                          |               |
| Poor             | 4.2 (3.6-4.8)         | 1.00                    | 5.0 (4.4-5.7)            | 1.00          |
| Intermediate     | 2.1 (1.9-2.4)         | 0.61 (0.51-0.74)        | 3.1 (2.8-3.4)            | 0.70 (0.59-0.82) |
| Ideal            | 1.0 (0.8-1.1)         | 0.36 (0.29-0.46)        | 1.3 (1.1-1.5)            | 0.39 (0.32-0.48) |

CVH, cardiovascular health; HR, hazard ratio; CI, confidence interval.

*Hazard ratios were estimated using Cox proportional hazards regression, adjusted for age, race, sex, education, income, history of coronary heart disease, and use of cardiovascular medications at baseline.

†Categorization of CVH metrics as poor, intermediate, or ideal are shown in Table S1.

†Incidence rates were calculated as events per 1000 person-years (95% confidence interval).
Table S4. Association of time varying individual CVH metrics with incidence of sudden cardiac death and non-sudden cardiac death

| CVH Metric         | Sudden Cardiac Death | Non-sudden Cardiac Death |
|--------------------|----------------------|--------------------------|
|                    | HR* (95% CI)         | HR* (95% CI)             |
| Smoking†           |                      |                          |
| Poor               | 1.00 (ref.)          | 1.00 (ref.)              |
| Intermediate       | 0.62 (0.49-0.79)     | 0.86 (0.69-1.08)         |
| Ideal              | 0.51 (0.39-0.66)     | 0.57 (0.45-0.73)         |
| Body mass index†   |                      |                          |
| Poor               | 1.00 (ref.)          | 1.00 (ref.)              |
| Intermediate       | 0.74 (0.60-0.92)     | 0.82 (0.68-1.00)         |
| Ideal              | 0.61 (0.47-0.80)     | 0.80 (0.64-1.00)         |
| Diet†              |                      |                          |
| Poor               | 1.00 (ref.)          | 1.00 (ref.)              |
| Intermediate       | 0.94 (0.75-1.17)     | 0.85 (0.69-1.04)         |
| Ideal              | 0.89 (0.61-1.30)     | 1.08 (0.80-1.47)         |
| Physical activity† |                      |                          |
| Poor               | 1.00 (ref.)          | 1.00 (ref.)              |
| Intermediate       | 1.06 (0.79-1.42)     | 0.93 (0.70-1.24)         |
| Ideal              | 0.64 (0.52-0.79)     | 0.81 (0.67-0.97)         |
| Blood glucose†     |                      |                          |
| Poor               | 1.00 (ref.)          | 1.00 (ref.)              |
| Intermediate       | 0.49 (0.39-0.61)     | 0.44 (0.36-0.54)         |
| Ideal              | 0.36 (0.28-0.45)     | 0.33 (0.27-0.41)         |
| Total cholesterol† |                      |                          |
| Poor               | 1.00 (ref.)          | 1.00 (ref.)              |
| Intermediate       | 1.13 (0.86-1.50)     | 0.75 (0.60-0.94)         |
| Ideal              | 0.77 (0.57-1.02)     | 0.62 (0.48-0.78)         |
| Blood pressure†    |                      |                          |
| Poor               | 1.00 (ref.)          | 1.00 (ref.)              |
| Intermediate       | 0.88 (0.71-1.08)     | 0.76 (0.64-0.91)         |
| Ideal              | 0.39 (0.29-0.55)     | 0.28 (0.20-0.39)         |

CVH, cardiovascular health; HR, hazard ratio; CI, confidence interval.

*Hazard ratios were estimated using time varying CVH in Cox proportional hazards regression with age as the time-scale, adjusted for age, race, sex, education, income, history of coronary heart disease, and use of cardiovascular medications at baseline.

†Categorization of CVH metrics as poor, intermediate, or ideal are shown in Table S1.
| Pattern of change | Poor-Poor | Poor-Intermediate/Ideal | Intermed. -Poor | Intermed-Intermediate | Intermed-Ideal | Ideal-Poor/Intermed | Ideal-Ideal |
|------------------|-----------|------------------------|----------------|---------------------|---------------|-------------------|------------|
| No. of subjects  | 4225      | 1261                   | 1873           | 2912                | 435           | 871               | 630        |
| Age, years       | 54.8 (5.6)| 55.0 (5.7)             | 53.6 (5.6)     | 53.9 (5.8)          | 54.1 (5.7)    | 52.4 (5.6)        | 52.2 (5.4) |
| Males, (%)       | 2236 (52.9)| 636 (50.4)            | 827 (44.2)     | 1192 (40.9)         | 162 (37.2)    | 263 (30.2)        | 167 (26.5) |
| Caucasians, (%)  | 2964 (70.2)| 903 (71.6)             | 1487 (79.4)    | 2421 (83.1)         | 375 (86.2)    | 783 (89.9)        | 584 (92.7) |
| Education, %     | <high school | 1197 (28.3)         | 381 (20.3)     | 437 (15.0)          | 47 (10.8)     | 90 (10.3)         | 30 (4.8)   |
|                  | high school/vocational school | 1721 (40.7) | 820 (43.8) | 1292 (44.4)         | 176 (40.5)    | 349 (40.1)        | 226 (35.9) |
|                  | College, graduate, or professional school | 1307 (30.9) | 672 (35.9) | 1183 (40.6)         | 212 (48.7)    | 432 (49.6)        | 374 (59.4) |
| Income (US$), %  | <16 000    | 1034 (24.5)            | 270 (21.4)     | 381 (20.3)          | 47 (10.8)     | 90 (10.3)         | 30 (4.8)   |
|                  | 16 000 to <25 000 | 651 (15.4)         | 245 (13.1)     | 410 (14.1)          | 58 (13.3)     | 101 (11.6)        | 62 (9.8)   |
|                  | 25 000 to <35 000 | 974 (23.1)          | 454 (24.2)     | 664 (22.8)          | 107 (24.6)    | 201 (23.1)        | 110 (17.5) |
|                  | 35 000 to <50 000 | 759 (18.0)          | 387 (20.7)     | 576 (19.8)          | 95 (21.8)     | 170 (19.5)        | 145 (23.0) |
|                  | ≥50 000    | 807 (19.1)             | 471 (25.2)     | 836 (28.7)          | 125 (28.7)    | 316 (36.3)        | 276 (43.8) |
| Smoking status, %| Never      | 1054 (25.0)            | 797 (42.6)     | 1533 (52.6)         | 280 (64.4)    | 609 (69.9)        | 516 (81.9) |
|                  | Former     | 2007 (47.5)            | 564 (30.1)     | 761 (26.1)          | 89 (20.5)     | 161 (18.5)        | 68 (10.8)  |
|                  | Current    | 1164 (27.6)            | 512 (27.3)     | 618 (21.2)          | 66 (15.2)     | 101 (11.6)        | 46 (7.3)   |
| Hypertension, %  | 2231 (52.8)| 492 (39.0)             | 499 (26.6)     | 593 (20.4)          | 55 (12.6)     | 51 (5.9)          | 27 (4.3)   |
| Diabetes, %      | 30.2 (5.1) | 28.2 (4.9)             | 27.7 (4.9)     | 26.1 (4.6)          | 24.4 (3.8)    | 24.2 (3.5)        | 22.7 (2.5) |
| Body mass index, | 32.0 (5.1) | 28.2 (4.9)             | 27.7 (4.9)     | 26.1 (4.6)          | 24.4 (3.8)    | 24.2 (3.5)        | 22.7 (2.5) |
| kg/m2            | Blood pressure, mmHg | 685 (16.2)         | 96 (5.1)       | 99 (3.4)            | 7 (1.6)       | 13 (1.5)          | 5 (0.8)    |
| Systolic         | 127.8 (18.1)| 124.1 (17.3)         | 118.6 (16.1)   | 115.9 (16.2)        | 111.8 (16.1)  | 108.8 (12.5)      | 105.8 (12.2) |
| Diastolic        | 76.7 (11.2) | 75.1 (10.8)            | 73.1 (10.2)    | 71.3 (10.0)         | 68.8 (10.4)   | 67.6 (8.7)        | 66.4 (8.4) |
| Fasting glucose, mg/dL | 117.1 (46.5)| 110.0 (41.0)        | 101.1 (26.4)   | 98.9 (25.0)         | 97.9 (20.4)   | 94.4 (16.6)       | 92.2 (10.7) |
| Total cholesterol, mg/dL | 223.8 (52.0)| 216.8 (48.6)       | 211.0 (42.9)   | 206.8 (44.1)        | 202.3 (40.0)  | 191.5 (33.4)      | 188.4 (35.5) |
| Medication, %    | β-Blocker  | 363 (8.6)             | 79 (6.3)       | 85 (4.5)            | 88 (3.0)      | 8 (1.8)           | 17 (2.0)   |
|                  | Calcium antagonist | 200 (4.7)         | 34 (2.7)       | 58 (3.1)            | 70 (2.4)      | 4 (0.9)           | 13 (1.5)   |
|                  | Digoxin    | 64 (1.5)              | 21 (1.7)       | 14 (0.8)            | 32 (1.1)      | 3 (0.7)           | 9 (1.0)    |
|                  | Antiarrhythmics | 35 (0.8)           | 3 (0.2)        | 11 (0.6)            | 16 (0.6)      | 4 (0.9)           | 7 (0.8)    |
Values are mean (SD) unless indicated otherwise.
| Pattern of change | Poor-Poor | Poor-Intermediate/Ideal | Intermediate-Poor | Intermediate-Intermediate | Intermediate-Ideal | Ideal-Poor/Intermediate | Ideal-Ideal |
|-------------------|-----------|-------------------------|-------------------|--------------------------|-------------------|-------------------------|-----------|
| Whole population  | 4225 (34.6%) | 1261 (10.3%) | 1873 (15.3%) | 2912 (23.9%) | 435 (3.6%) | 871 (7.1%) | 630 (5.2%) |
| Sex               |           |                        |                   |                          |                   |                         |           |
| Males             | 2236 (40.8%) | 636 (11.6%) | 827 (15.1%) | 1192 (21.7%) | 162 (3.0%) | 263 (4.8%) | 167 (3.1%) |
| Females           | 1989 (30.0%) | 625 (9.3%) | 1046 (15.6%) | 1720 (25.6%) | 273 (4.1%) | 608 (9.0%) | 463 (6.9%) |
| Race              |           |                        |                   |                          |                   |                         |           |
| Caucasians        | 2964 (31.1%) | 903 (9.5%) | 1487 (15.6%) | 2421 (25.4%) | 375 (3.9%) | 783 (8.2%) | 584 (6.1%) |
| Blacks            | 1261 (46.9%) | 358 (13.3%) | 386 (14.4%) | 491 (18.3%) | 60 (2.2%) | 88 (3.3%) | 46 (1.7%) |
| Age               |           |                        |                   |                          |                   |                         |           |
| >=55              | 2217 (38.8%) | 685 (12.0%) | 789 (13.8%) | 1317 (23.0%) | 204 (3.6%) | 299 (5.2%) | 204 (3.6%) |
| <55               | 2008 (30.9%) | 576 (8.9%) | 1084 (16.7%) | 1595 (24.6%) | 231 (3.6%) | 572 (8.8%) | 426 (6.6%) |

CVH, cardiovascular health
Table S7. Change in the level of individual CVH metrics between 1987/89 and 1993/95

| Pattern of change | Poor-Poor | Poor-Intermediate/Ideal | Intermediate-Poor | Intermediate-Ideal | Ideal-Poor/Ideal | Ideal-Ideal |
|-------------------|-----------|-------------------------|-------------------|-------------------|-----------------|------------|
| **CVH metric, No. (%)** |           |                         |                   |                   |                 |            |
| Smoking           | 1977 (16.2) | 841 (6.9)           | 170 (1.4)         | 3786 (31.0)       | 140 (1.2)       | 484 (4.0)  |
| Body mass index   | 2961 (24.3) | 281 (2.3)           | 1055 (8.6)        | 3453 (28.3)       | 384 (3.2)       | 1115 (9.1) |
| Diet              | 1036 (8.5)  | 1447 (11.9)         | 1428 (11.7)       | 6324 (51.8)       | 766 (6.3)       | 906 (7.4)  |
| Physical activity | 2620 (21.5) | 1753 (11.4)        | 367 (3.0)         | 137 (1.1)         | 481 (3.9)       | 2115 (17.3)|
| Blood glucose     | 808 (6.6)   | 215 (1.8)           | 696 (5.7)         | 2725 (22.3)       | 1357 (11.1)     | 1925 (15.8)|
| Total cholesterol | 1359 (11.1) | 1528 (12.5)        | 671 (5.5)         | 2814 (23.1)       | 1411 (11.6)     | 1116 (9.5) |
| Blood pressure    | 1069 (8.8)  | 853 (7.0)           | 1165 (9.5)        | 2947 (24.1)       | 634 (5.2)       | 1898 (15.6)|
|                   |            |                       |                   |                   |                 | 3641 (29.8)|
Table S8. Change in CVH status between 1987/89 and 1993/95, and association with sudden cardiac death and non-sudden cardiac death (competing risk analysis)

| Change in CVH Status*          | Sudden Cardiac Death |                | Non-sudden Cardiac Death |                |
|--------------------------------|----------------------|----------------|--------------------------|----------------|
|                                | Events/subjects      | Incidence rate per 1000 person-year | Adjusted HR (95% CI) | Events/subjects      | Incidence rate per 1000 person-year | Adjusted HR (95% CI) |
| Consistently poor              | 202/4225             | 3.3 (2.9-3.8) | 1.00 (ref.)              | 271/4225             | 4.4 (3.9-5.0) | 1.00 (ref.) |
| Poor to intermediate/ideal     | 41/1261              | 2.2 (1.6-3.0) | 0.69 (0.49-0.97)         | 59/1261              | 3.1 (2.4-4.1) | 0.73 (0.55-0.97) |
| Intermediate to poor           | 55/1873              | 1.9 (1.5-2.5) | 0.75 (0.55-1.01)         | 64/1873              | 2.2 (1.7-2.8) | 0.61 (0.46-0.80) |
| Consistently intermediate      | 55/2912              | 1.2 (0.9-1.6) | 0.50 (0.37-0.68)         | 74/2912              | 1.6 (1.3-2.0) | 0.46 (0.35-0.59) |
| Intermediate to ideal          | 8/435                | 1.2 (0.6-2.3) | 0.52 (0.26-1.05)         | 12/435               | 1.8 (1.0-3.1) | 0.51 (0.28-0.90) |
| Ideal to poor/intermediate     | 6/871                | 0.4 (0.2-0.9) | 0.24 (0.10-0.54)         | 14/871               | 1.0 (0.6-1.7) | 0.36 (0.21-0.61) |
| Consistently ideal             | 6/630                | 0.5 (0.2-1.2) | 0.32 (0.13-0.79)         | 7/630                | 0.7 (0.3-1.4) | 0.28 (0.13-0.60) |

**Change in No. of Ideal Metrics†**

| Per 1 additional ideal metric  | 302/12207            | 2.0 (1.8-2.2) | 0.84 (0.72-0.96)         | 501/12207            | 2.7 (2.5-2.9) | 0.90 (0.80-1.01) |

**Change in 14-point CVH Score†**

| Per 1-point increase in score  | 302/12207            | 2.0 (1.8-2.2) | 0.83 (0.75-0.92)         | 501/12207            | 2.7 (2.5-2.9) | 0.89 (0.82-0.97) |

CVH, cardiovascular health; HR, hazard ratio; CI, confidence interval.

*Adjustment for age, race, sex, education, income, history of coronary heart disease, and use of cardiovascular medications at baseline.

†Further adjustment for number of ideal metrics and CVH score at baseline.
Table S9. Change in CVH status between 1987/89 and 1993/95, and association with sudden cardiac death and non-sudden cardiac death (stratified analyses by sex)

| CVH Status*                  | Sudden Cardiac Death | Non-sudden Cardiac Death |
|------------------------------|----------------------|--------------------------|
|                              | Events/subjects      | Incidence rate per 1000 person-year (95% CI) | Adjusted HR (95% CI) | Events/subjects      | Incidence rate per 1000 person-year (95% CI) | Adjusted HR (95% CI) |
| Males                        |                      |                          |                      |                      |                          |                      |
| Consistently poor            | 135/2236             | 4.2 (3.5-5.0)            | 1.00 (ref.)          | 157/2236             | 4.9 (4.2-5.7)            | 1.00 (ref.)          |
| Poor to intermediate/ideal   | 33/636               | 3.6 (2.5-5.0)            | 0.83 (0.56-1.21)     | 34/636               | 3.7 (2.5-5.1)            | 0.72 (0.50-1.05)     |
| Intermediate to poor         | 33/827               | 2.7 (1.8-3.7)            | 0.69 (0.47-1.01)     | 38/827               | 3.1 (2.2-4.2)            | 0.69 (0.48-0.98)     |
| Consistently intermediate    | 30/1192              | 1.6 (1.1-2.3)            | 0.43 (0.29-0.63)     | 37/1192              | 2.0 (1.4-2.8)            | 0.45 (0.31-0.64)     |
| Intermediate to ideal        | 5/162                | 1.9 (0.6-4.5)            | 0.51 (0.21-1.25)     | 7/162                | 2.7 (1.1-5.6)            | 0.59 (0.28-1.26)     |
| Ideal to poor/intermediate   | 4/263                | 1.0 (0.3-2.4)            | 0.28 (0.10-0.76)     | 7/263                | 1.7 (0.7-3.5)            | 0.43 (0.20-0.92)     |
| Consistently ideal           | 2/167                | 0.8 (0.1-2.7)            | 0.24 (0.06-0.98)     | 3/167                | 1.1 (0.2-3.3)            | 0.33 (0.10-1.03)     |
| Change in No. of Ideal Metrics† | 242/5483             | 3.0 (2.6-3.4)             | 0.86 (0.73-1.01)     | 283/5483             | 3.5 (3.1-3.9)             | 0.94 (0.80-1.09)     |
| Females                      |                      |                          |                      |                      |                          |                      |
| Consistently poor            | 67/1989              | 2.3 (1.8-2.9)            | 1.00 (ref.)          | 114/1989             | 3.9 (3.2-4.7)            | 1.00 (ref.)          |
| Poor to intermediate/ideal   | 8/625                | 0.8 (0.4-1.7)            | 0.41 (0.19-0.85)     | 25/625               | 2.6 (1.7-3.9)            | 0.67 (0.43-1.03)     |
| Intermediate to poor         | 22/1046              | 1.3 (0.8-2.0)            | 0.87 (0.54-1.42)     | 26/1046              | 1.6 (1.0-2.3)            | 0.49 (0.32-0.76)     |
| Consistently intermediate    | 25/1720              | 0.9 (0.6-1.4)            | 0.65 (0.41-1.05)     | 37/1720              | 1.4 (1.0-1.9)            | 0.43 (0.29-0.63)     |
| Intermediate to ideal        | 3/273                | 0.7 (0.1-2.0)            | 0.57 (0.18-1.84)     | 5/273                | 1.2 (0.4-2.7)            | 0.38 (0.16-0.95)     |
| Ideal to poor/intermediate   | 2/608                | 0.2 (0.0-0.7)            | 0.21 (0.05-0.85)     | 7/608                | 0.7 (0.3-1.4)            | 0.27 (0.13-0.60)     |
| Consistently ideal           | 3/463                | 0.4 (0.1-1.2)            | 0.47 (0.14-1.54)     | 4/463                | 0.5 (0.1-1.4)            | 0.23 (0.08-0.62)     |
| Change in No. of Ideal Metrics† | 242/5483             | 3.0 (2.6-3.4)             | 0.86 (0.73-1.01)     | 283/5483             | 3.5 (3.1-3.9)             | 0.84 (0.70-1.00)     |

CVH, cardiovascular health; HR, hazard ratio; CI, confidence interval.
*Adjustment for age, race, education, income, history of coronary heart disease, and use of cardiovascular medications at baseline.
†Further adjustment for number of ideal metrics and CVH score at baseline.
Table S10. Change in CVH status between 1987/89 and 1993/95, and association with sudden cardiac death and non-sudden cardiac death (stratified analyses by race)

|                  | Sudden Cardiac Death |                  |                    | Non-sudden Cardiac Death |                  |                    |
|------------------|----------------------|------------------|-------------------|--------------------------|------------------|-------------------|
|                  | Events/subjects      | Incidence rate per 1000 person-year | Adjusted HR (95% CI) |                  | Events/subjects      | Incidence rate per 1000 person-year | Adjusted HR (95% CI) |
|                  |                      |                  |                    |                          |                  |                    |
| Caucasians       |                      |                  |                    |                          |                  |                    |
| Change in CVH Status* |                      |                  |                    |                          |                  |                    |
| Consistently poor | 115/2964             | 2.6 (2.2-3.1)    | 1.0 (ref.)         | 175/2964                 | 4.0 (3.4-4.6)    | 1.00 (ref.)        |
| Poor to intermediate/ideal | 25/903             | 1.9 (1.2-2.7)    | 0.77 (0.50-1.19)   | 43/903                   | 3.2 (2.3-4.3)    | 0.82 (0.59-1.15)   |
| Intermediate to poor | 34/1487            | 1.5 (1.0-2.0)    | 0.70 (0.48-1.03)   | 47/1487                  | 2.0 (1.5-2.7)    | 0.61 (0.44-0.84)   |
| Consistently intermediate | 38/2421        | 1.0 (0.7-1.4)    | 0.50 (0.34-0.72)   | 63/2421                  | 1.7 (1.3-2.1)    | 0.49 (0.37-0.66)   |
| Intermediate to ideal | 7/375              | 1.2 (0.5-2.4)    | 0.62 (0.29-1.33)   | 9/375                    | 1.5 (0.7-2.8)    | 0.46 (0.23-0.90)   |
| Ideal to poor/intermediate | 6/783           | 0.5 (0.2-1.0)    | 0.30 (0.13-0.69)   | 12/783                   | 0.9 (0.5-1.6)    | 0.55 (0.19-0.63)   |
| Consistently ideal | 5/584               | 0.5 (0.2-1.2)    | 0.40 (0.16-0.98)   | 6/584                    | 0.6 (0.2-1.4)    | 0.27 (0.12-0.62)   |
| Change in No. of Ideal Metrics† |                  |                  |                    |                          |                  |                    |
| Per 1 additional ideal metric | 230/9517         | 1.6 (1.4-1.8)    | 0.85 (0.71-1.00)   | 355/9517                 | 2.4 (2.2-2.7)    | 0.91 (0.80-1.05)   |
| Change in 14-point CVH Score† |                  |                  |                    |                          |                  |                    |
| Per 1-point increase in score | 230/9517          | 1.6 (1.4-1.8)    | 0.85 (0.75-0.96)   | 355/9517                 | 2.4 (2.2-2.7)    | 0.90 (0.81-1.00)   |
| Blacks           |                      |                  |                    |                          |                  |                    |
| Change in CVH Status* |                      |                  |                    |                          |                  |                    |
| Consistently poor | 87/1261             | 5.0 (4.0-6.1)    | 1.00 (ref.)        | 96/1261                  | 5.5 (4.4-6.7)    | 1.00 (ref.)        |
| Poor to intermediate/ideal | 16/358            | 3.0 (1.7-4.9)    | 0.58 (0.34-1.00)   | 16/358                   | 3.0 (1.7-4.9)    | 0.51 (0.30-0.87)   |
| Intermediate to poor | 21/386             | 3.7 (2.3-5.6)    | 0.83 (0.51-1.34)   | 17/386                   | 3.0 (1.7-4.8)    | 0.61 (0.37-1.03)   |
| Consistently intermediate | 17/491          | 2.3 (1.4-3.7)    | 0.51 (0.30-0.87)   | 11/491                   | 1.5 (0.8-2.7)    | 0.30 (0.16-0.56)   |
| Intermediate to ideal | 1/60                | 1.2 (0-6.4)      | 0.25 (0.03-1.77)   | 3/60                     | 3.5               | 0.64 (0.20-2.02)   |
| Ideal to poor/intermediate | 0/88               | 0 (0-2.6)        | NA                 | 2/88                     | 1.4 (0-5.1)      | 0.38 (0.09-1.54)   |
| Consistently ideal | 0/46                | 0 (0-5.3)        | NA                 | 1/46                     | 1.5 (0-8.1)      | 0.36 (0.05-2.63)   |
| Change in No. of Ideal Metrics† |                  |                  |                    |                          |                  |                    |
| Per 1 additional ideal metric | 142/2690         | 3.7 (3.1-4.3)    | 0.82 (0.65-1.02)   | 146/2690                 | 3.8 (3.2-4.4)    | 0.83 (0.67-1.03)   |
| Change in 14-point CVH Score† |                  |                  |                    |                          |                  |                    |
| Per 1-point increase in score | 142/2690          | 3.7 (3.1-4.3)    | 0.80 (0.69-0.94)   | 146/2690                 | 3.8 (3.2-4.4)    | 0.84 (0.72-0.98)   |
CVH, cardiovascular health; HR, hazard ratio; CI, confidence interval.

*Adjustment for age, race, education, income, history of coronary heart disease, and use of cardiovascular medications at baseline.

†Further adjustment for number of ideal metrics and CVH score at baseline.
Figure S1. Forest plot of adjusted hazard ratios (HRs) of change in cardiovascular health (CVH) status between 1987/89 and 1993/95 and subsequent risk of sudden cardiac death (A) and non-sudden cardiac death (B)

(A) Sudden Cardiac Death

| Incidence | Rate per 1000 | Person-Years (95% CI) | HR (95%CI) |
|-----------|---------------|------------------------|------------|
| Events/subjects | Consistently poor | 202/4225 | 3.3 (2.9-3.8) | 1.00 (ref.) |
| | Poor to intermediate/ideal | 41/1261 | 2.2 (1.6-3.0) | 0.67 (0.48-0.94) |
| | Intermediate to poor | 55/1873 | 1.9 (1.5-2.5) | 0.73 (0.54-0.99) |
| | Consistently intermediate | 55/2912 | 1.2 (0.9-1.6) | 0.49 (0.36-0.66) |
| | Intermediate to ideal | 8/435 | 1.2 (0.6-2.3) | 0.49 (0.24-0.96) |
| | Ideal to poor/intermediate | 6/871 | 0.4 (0.2-0.9) | 0.23 (0.10-0.52) |
| | Consistently ideal | 6/630 | 0.5 (0.2-1.2) | 0.31 (0.13-0.76) |


(A) Non-Sudden Cardiac Death

| Incidence | Rate per 1000 | Person-Years (95% CI) | HR (95%CI) |
|-----------|---------------|------------------------|------------|
| Events/subjects | Consistently poor | 271/4225 | 4.4 (3.9-5.0) | 1.00 (ref.) |
| | Poor to intermediate/ideal | 58/1261 | 3.1 (2.4-4.1) | 0.71 (0.54-0.94) |
| | Intermediate to poor | 64/1873 | 2.2 (1.7-2.8) | 0.61 (0.46-0.80) |
| | Consistently intermediate | 74/2912 | 1.6 (1.3-2.0) | 0.45 (0.34-0.58) |
| | Intermediate to ideal | 12/435 | 1.8 (1.0-3.1) | 0.49 (0.27-0.87) |
| | Ideal to poor/intermediate | 14/871 | 1.0 (0.6-1.7) | 0.35 (0.20-0.65) |
| | Consistently ideal | 7/630 | 0.7 (0.3-1.4) | 0.27 (0.13-0.58) |