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Association of the "life's crucial 9" cardiovascular health with all-cause and cardiovascular disease mortality: a national cohort study

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Abstract

Background In 2022, the American Heart Association launched an updated algorithm for quantifying cardiovascular health (CVH), termed Life's Essential 8 (LE8). This new approach has been shown to be associated with various noncommunicable chronic diseases and mortality. However, LE8 did not take into consideration the importance of psychological health on CVH. Recently, a perspective article proposed Life's Crucial 9 (LC9), which would add psychological health as another component to LE8, as a novel metric to assess CVH. This study aims to investigate the association of LC9 with all-cause and cardiovascular disease (CVD) mortality.

Methods This study included 23,080 adults from National Health and Nutrition Examination Survey 2005–2018, and mortality was ascertained by linkage to National Death Index records through 31 December 2019. The LC9 scoring algorithm was categorized into low (0–49), moderate (50–79), and high (80–100) CVH. Weighted Cox proportional hazards regression models and restricted cubic spline analysis were applied to evaluate the association of LC9 with mortality.

Results During a median follow-up of 7.8 years, a total of 2,388 overall deaths were identified, covering 613 CVD deaths. Compared with adults with a low CVH score, those with a high CVH score had 52% (hazard ratio, 0.48; 95% confidence interval, 0.38–0.60) and 64% (0.36; 0.23–0.56) reduced risk of all-cause and CVD mortality. Similarly, a moderate CVH score was associated with 33% (0.67; 0.58–0.78) and 49% (0.51; 0.40–0.64) reduced risk of all-cause and CVD mortality. The population-attributable fractions of high vs. moderate or low CVH score were 46.0% for all-cause mortality and 75.8% for CVD mortality. Elevated blood lipids, high body mass index, and poor sleep quality were the three major contributors to all-cause mortality, whereas nicotine exposure, unhealthy psychology, and elevated blood lipids were the three significant ones to CVD mortality. There were approximately negative linear dose-response relationships of total LC9 score with all-cause and CVD mortality.

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Conclusions Adhering to a high LC9 score is related to a reduced risk of all-cause and CVD mortality. This new CVH definition shows promise as a primordial preventive strategy to reduce mortality rates.

Keywords Cardiovascular health, Life's crucial 9, All-cause mortality, Cardiovascular disease mortality, National health and nutrition examination survey

Text box 1. Contributions to the literature

- All-cause and cardiovascular disease (CVD) mortality was significantly decreased in high and moderate Life's Crucial 9 (LC9) score groups compared to low LC9 score group.
- Restricted Cubic Splines RCS (RCS) analysis showed an almost linear relationship between LC9 scores and mortality.
- Population Attributable Fraction (PAF) analysis indicated that several factors, including elevated blood lipids, high body mass index, poor sleep quality, nicotine exposure, unhealthy psychology, contributed significantly to all-cause or CVD mortality.
- Compared to Life's Essential 8 (LE8), LC9 score demonstrated better predictive performance for mortality outcomes.

Introduction

As highlighted in the 2022 Global Burden of Disease (GBD) report, cardiovascular disease (CVD) continued to be the predominant contributor to the global disease burden. CVD is estimated to affect 48.6% of the general adult population in the United States (US), posing a significant threat to both the economy and society [1]. Unhealthy lifestyle patterns such as poor diet, physical inactivity, smoking, insufficient sleep duration, obesity, dyslipidemia, diabetes, and hypertension have been pinpointed as major CVD risk factors [2, 3]. Consequently, the American Heart Association (AHA) has emphasized the importance of mitigating these lifestyle-related risk factors in its guidelines for the prevention of CVD [4].

In 2022, the AHA updated the concept of optimal cardiovascular health (CVH), which is achieved by the simultaneous presence of four key health behaviors (healthy diet, physical activity, avoidance of nicotine exposure, and healthy sleep patterns) and four critical health factors (normal body mass index [BMI], favorable blood lipids, stable blood glucose levels, and controlled blood pressure) [5]. This new CVH construct, termed Life's Essential 8 (LE8), has been demonstrated to be related to CVD, non-CVD noncommunicable diseases (NCDs), all-cause mortality, and CVD mortality [6, 7, 8, 9]. Notably, participants in high CVH status (LE8 score ≥ 80) had an average 8.9 more years of life expectancy at age 50 years compared with those in low CVH status (LE8 score < 50) [9].

In introducing the novel scoring algorithm, the AHA underscored the pivotal role of psychological health in attaining optimal CVH among populations. A comprehensive review of observational and experimental studies conducted by the AHA over four decades revealed that psychological health factors significantly influence CVD risk, onset, and recurrence [10]. However, given the multifaceted nature of psychological health and the uncertainty about which phenotype in psychological health most affects CVH, the AHA has not yet integrated psychological health into the new CVH construct. Recently, a perspective article in Circulation [11] noted that such an approach overlooked the effects of psychological health on CVH, suggesting that a singular, reliable, and representative psychological phenotype could be employed to gauge psychological health. Concurrently, the US Preventive Services Task Force has identified that depression and anxiety had great adverse effects on CVH [12]. Furthermore, a previous National Health and Nutrition Examination Survey (NHANES) study by Lloyd-Jones et al. highlighted that depression was one of the more reliable psychological phenotypes measured in NHANES [13]. Consequently, we posit that utilizing depression as a metric for assessing psychological health in NHANES is a viable and practical approach.

In our study, we employed a standardized metric for depression to evaluate psychological health. The new concept of CVH, which combines psychological health with the eight components in LE8, is referred to as Life's Crucial 9 (LC9) [11]. Based on nationally representative data from NHANES and the new CVH scoring algorithm, we investigated the association of the LC9 score with all-cause and CVD mortality among US adults. In addition, population attributable fractions (PAFs) of each component in LC9 were calculated and ranked to determine the priority in relation to mortality risk.

Methods

Study design and participants

The NHANES is an ongoing cross-sectional survey administered by the National Center for Health Statistics of the Centers for Disease Control and Prevention. This survey uses a complex, stratified, multistage, and probability-cluster design to collect nationally representative data on the health and nutritional status of the civilian non-institutionalized United States population (https://www.cdc.gov/nchs/nhanes). Participants in NHANES completed a questionnaire at home, followed by a physical examination and laboratory assessment at a mobile exam center. Written informed consent to participate was obtained from each participant.

As NHANES started to conduct interviews on sleep health in the 2005–2006 survey cycle, participants in the NHANES (2005–2018) were included in this study.

Of the 70,190 participants from NHANES 2005–2018, 39,749 participants aged 20 years or older were included. We further excluded participants based on the following criteria: (1) pregnant at baseline ($n = 711$); (2) information on death status or follow-up years was unavailable ($n = 1,645$); (3) participants with insufficient information for all nine LC9 metrics ($n = 11,656$); (4) missing information on potential covariates ($n = 2,657$). Finally, a total of 23,080 adults were eligible for this study (Fig. 1).

Measurement of LC9

According to Gaffey et al. [11], the LC9 scoring algorithm consists of nine components: diet, physical activity, nicotine exposure, sleep health, BMI, non-high-density lipoprotein (non-HDL) cholesterol, blood glucose, blood pressure, and psychological health.

Dietary intake was collected via the average of two non-consecutive 24-h recalls, and dietary quality was assessed by using the Healthy Eating Index 2015 (HEI-2015), which measures adherence to recommendations in the 2015–2020 Dietary Guidelines for Americans [14]. Information on physical activity (self-reported minutes per week of moderate-to-vigorous physical activity), nicotine exposure (combustible cigarette use, inhaled nicotine delivery systems use, and secondhand smoke exposure) and sleeping information (sleep duration) was obtained from self-report questionnaires. Blood pressure, height and weight were measured during the physical examination at the mobile examination center. The average of 3 blood pressure measurements were utilized to assess systolic and diastolic blood pressure, and the body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. Blood lipid and glycemic profiles were measured at a morning examination session after fasting for 9 h or more. The non-HDL cholesterol was calculated by subtracting HDL cholesterol from total cholesterol, and Hemoglobin A1c (HbA1c) was utilized to evaluate blood glucose levels. As an incremental version of LE8, LC9 incorporates psychological health as the nineth indicator in the CVH metrics [11]. According to Ryff and Keyes [15], psychological health can be understood in terms of two perspectives, including negative psychological health (depression, anxiety, pessimism, anger, hostility, any-cause stress, etc.) and positive psychological health (optimism, happiness, mindfulness, sense of purpose, higher emotional vitality, etc.). Despite depression being only one aspect of psychological health, it is one of the more reliable psychological phenotypes measured in NHANES, which does not yet routinely measure other aspects of psychological health [13]. Therefore, the degree of depression was used to measure the psychological health. Depression was defined by the Patient Health Questionnaire-9 (PHQ-9), a prevalent self-report instrument for assessing depression levels in the general population [16].

Detailed algorithms for calculating the LC9 scores for the 9 indicators in the NHANES data have been previously published and can be found in Additional file 1: Table S1 [5, 13]. Particularly, the depression score was calculated based on the PHQ-9 score. It was assigned as 100, 60, 40, 20, and 0 corresponding to 0 to 4, 5 to 9, 10 to 14, 15 to 19, and 20 to 27 in PHQ-9 score, respectively. Each of the 9 indicators was scored ranging from 0 to 100 points, and the total LC9 score was calculated as an unweighted average of the 9 indicators. Participants with LC9 scores of 80 to 100 were categorized as having high CVH, scores of 50 to 79 as moderate CVH, and scores of 0 to 49 as low CVH, following the American Heart Association's recommendations [5].

Ascertainment of mortality

The primary outcome of the current study was all-cause and cardiovascular mortality. We used the NHANES public-use linked mortality file as of December 31, 2019, which was linked by the NCHS to the National Death Index (NDI) with a probabilistic matching algorithm to determine the mortality status [17]. Previous study has proved that the cause-specific mortality in the NDI have the accurate results in death of classification and relatively small possibility of misclassification [18]. All-cause mortality was defined as deaths attributable to any cause. CVD mortality was defined as the death attributed to heart diseases (I00 to I09, I11, I13, I20 to I51) and cerebrovascular diseases (I60 to I69), according to the International Classification of Diseases, 10th edition (ICD-10). People who survived were administratively censored on 31 December, 2019. Follow-up time for each person was calculated as the difference between the NHANES baseline examination date and the last known date alive or censored from the NHANES mortality file.

Assessments of covariates

Covariates were chosen based on previous literature of CVH and depression [19, 20], including age, sex (male and female), ethnicity (non-Hispanic White, non-Hispanic Black, Mexican American, and other), educational level (less than high school, high school or equivalent, and college or above), family income to poverty ratios (< 1, 1 to 3, and > 3), marital status (coupled and single or separated), alcohol status, hypertension, diabetes, CVD, and cancer. Alcohol status was categorized as non-drinker, heavy drinker (≥ 3 drinks per day for females, ≥ 4 drinks per day for males, or binge drinking [≥ 4 drinks on same occasion for females, ≥ 5 drinks on same occasion for males] on 5 or more days per month), and low to moderate drinker (not meet the criterion above). Participants were considered to have hypertension when at least

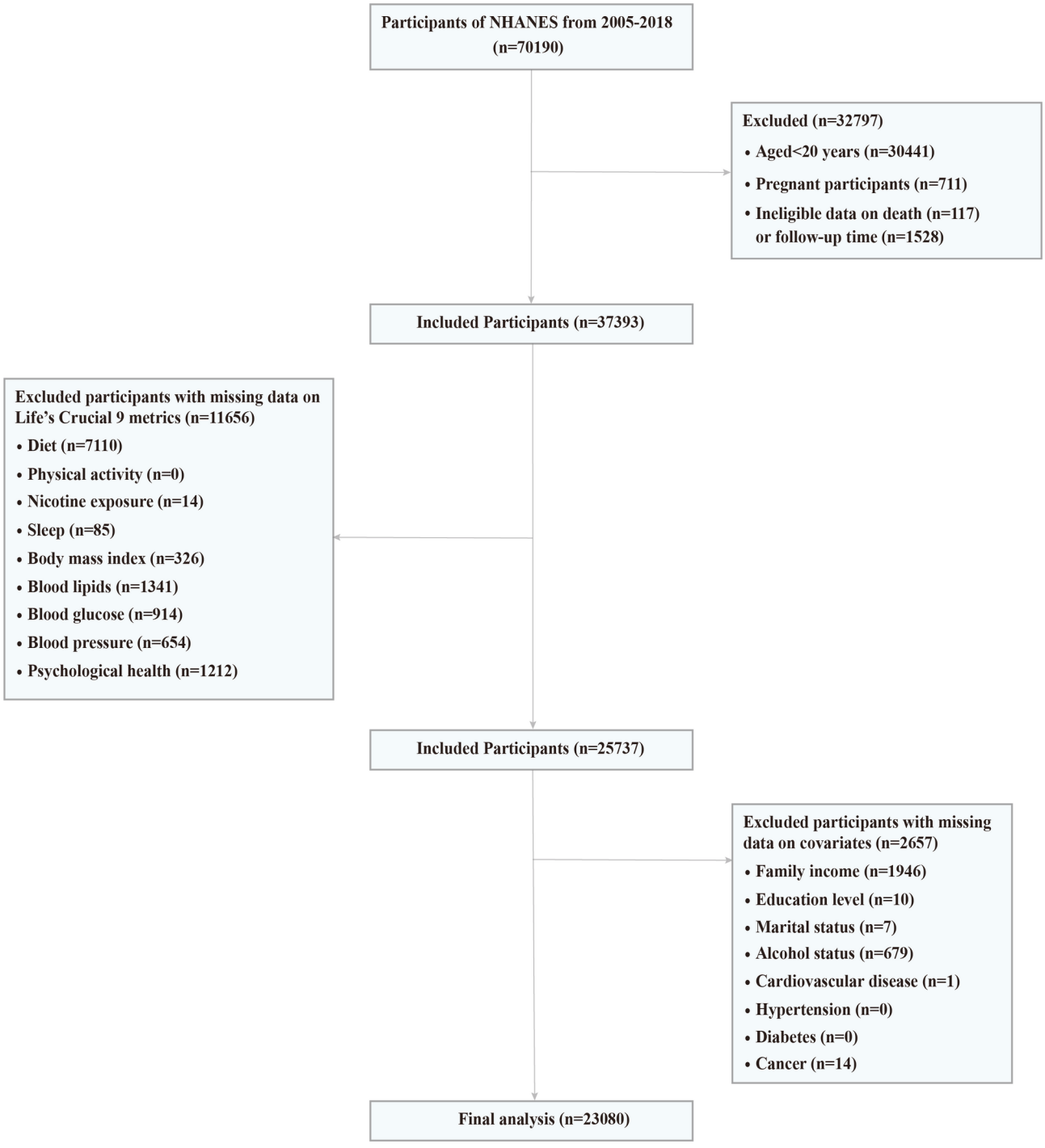

Fig. 1 Flow chart of participants in the association of the "Life's Crucial 9" cardiovascular health with all-cause and cardiovascular disease mortality in the United States: National Health and Nutrition Examination Survey cohort study 2005–2018. Abbreviation: NHANES, National Health and Nutrition Examination Survey

one of three criteria was met: (1) average systolic blood pressure ≥ 140 mmHg or average diastolic blood pressure ≥ 90 mmHg; (2) already on prescribed antihypertensive medications; (3) told to have hypertension by a doctor or other health professional. Diabetes was defined as self-reported doctor diagnosis of diabetes, use of oral hypoglycemic medication or insulin, fasting plasma glucose ≥ 126 mg/dL, random blood glucose ≥ 200 mg/dL, two-hour oral glucose tolerance test blood glucose ≥ 200 mg/dL, or glycated hemoglobin A1c ≥ 6.5%. CVD and cancer were identified through self-reporting.

Statistical analysis

All analyses incorporated sample weights, clustering, and stratification of the complex sampling design to ensure nationally representative estimates. For baseline characterization, weighted means with standard errors (SE) were used for continuous variables, and weighted percentages were used for categorical variables. To check for differences in characteristics between the three CVH groups, Analysis of Variance was used for differences in weighted means for continuous variables and the Rao-Scott Chi-Square test for differences in weighted percentages for categorical variables. Survey-weighted Cox regression analysis was implemented to calculate hazard ratios (HR) along with their corresponding 95% confidence intervals (CI) for assessing the associations of LC9 with all-cause and CVD mortality. Schoenfeld residuals were used to test the proportional hazards assumption, and no violation were observed. Three models were constructed: an unadjusted model (Crude Model), an age, sex, and ethnicity-adjusted model (Model 1), and a comprehensive adjustment for potential confounders (Model 2), encompassing age, sex, ethnicity, education level, family income, marital status, alcohol status, hypertension, diabetes, CVD and cancer. The probabilities of survival were calculated and plotted according to the Kaplan-Meier method. Besides, to comprehensively understand the relationship between LC9 and mortality risk, restricted cubic spline (RCS) models were utilized to estimate the dose-response association of total LC9 score with all-cause and CVD mortality. We used the Akaike information criterion (AIC) to select the RCS with specific number of knots and adopted the model with the lowest AIC criterion value, which is considered as the best-fitting RCS model.

Subgroup analyses were performed to examine the association of total LC9 score with all-cause and CVD mortality stratified by age, sex, ethnicity, education level, family income, marital status, alcohol status, hypertension, diabetes, CVD and cancer. Besides, a series of sensitivity analyses were conducted to test the robustness of our findings. First, participants who died within 2 years of baseline examination were excluded to minimize reverse causality. Second, we excluded the participants with comorbidity (including hypertension, diabetes, CVD and cancer). Third, considering the potential impact of medication on CVD and mortality, we conducted a sensitivity analysis that excluded participants treated with antiplatelet medications, angiotensin-converting enzyme inhibitors, beta-blockers, statins, and glucocorticoids. Fourth, exclusion of eligible participants with missing data on covariates may introduce selection bias. To remedy missing data problems, multivariate single imputation was performed using a machine learning algorithm via the R package 'missRanger'. Fifth, considering the multifaceted nature of psychological health, simply using depression to evaluate psychological health is not sufficient. We employed anxiety to assess psychological health using data from NHANES 2007–2012.

The adjusted population-attributable fractions (PAFs) of high CVH score (≥ 80 points) vs. moderate or low CVH score (< 80 points) were calculated to quantify the proportion of all-cause and CVD mortality in a population attributable to the 9 components of LC9 scoring algorithm. This well-established approach was developed by Eide and Gefeller [21] and realized with 'graphPAF' R package. In addition, to determine whether the psychological health in addition to LE8 can improve the prediction of all-cause and CVD mortality, the receiver operating characteristic (ROC) curve analysis was performed to determine the area-under-the-curve (AUC) to evaluate the Cox model's performance. The ROC curve for LE8 and LC9 score was performed via 'timeROC' R package, and the Delong test was used for the statistical comparison of ROC curves by the the R package 'pROC'. We further used Net Reclassification Improvement (NRI) method to evaluate the prognostic value of the depression score in addition to LE8 for all-cause and CVD mortality via the R package 'survNRI' [22]. This R package can calculate the NRI with 95% CI using five different estimators: Kaplan-Meier estimator, Inverse probability weighted estimator, Smooth inverse probability weighted estimator, Semi-parametric estimator, and Combined estimator. The model prediction statistics were calculated for the median duration of follow-up.

All analyses were performed using the R software, version 4.2.2 (R Core Team, Vienna, Austria). A two-sided $P < 0.05$ was considered statistically significant.

Results

Basic characteristics

Table 1 demonstrated the baseline characteristics of the 23,080 adults grouped by low (8.74%), moderate (68.29%), and high CVH (22.97%). Compared to the participants in the low CVH group, those in the high CVH group were more likely to be younger, female, non-Hispanic White, coupled, non-heavy drinkers, and have a high education level and high household income. In terms of comorbidities, high CVH participants were less likely to have hypertension, diabetes, CVD, and cancer. Besides, participants with a high CVH exhibited characteristics of lower BMI, non-HDL cholesterol, HbA1c, blood pressure level, and a higher HEI-2015 score and PHQ9 score, as well as longer physical activity and sleep duration (all $P \leq 0.0001$).

Association of LC9 with all-cause and CVD mortality

During a median follow-up of 7.8 years, a total of 2,388 deaths were identified, covering 613 (25.7%) CVD deaths. Compared to the low CVH group, after adjusting for

Table 1 Baseline demographic, lifestyle, and medical characteristics of participants by different levels of cardiovascular health estimated by the life's crucial 9 score in the united States National health and nutrition examination survey 2005–2018 cohort

Characteristic	LC9 score			*P* value
	0–49	50–79	80–100	
No. of participants	2018	15,761	5301	
Prevalence, %	8.74	68.29	22.97	
Age (years), mean (SE)	53.59(0.43)	49.22(0.26)	42.38(0.40)	< 0.0001
Sex, n (%)				< 0.0001
Female	1134(57.89)	7582(48.39)	3008(57.17)	
Male	884(42.11)	8179(51.61)	2293(42.83)	
Race or ethnicity, n (%)				< 0.0001
Mexican American	239(6.28)	2421(7.83)	718(6.85)	
Non-Hispanic Black	578(15.95)	3387(10.72)	667(5.79)	
Non-Hispanic White	933(68.26)	7335(71.05)	2580(73.76)	
Other	268(9.50)	2618(10.41)	1336(13.61)	
Education level, n (%)				< 0.0001
Less than high school	695(25.85)	3629(15.12)	614(6.78)	
High school or equivalent	562(32.26)	3968(25.86)	771(13.15)	
College or above	761(41.89)	8164(59.01)	3916(80.07)	
Family PIR, n (%)				< 0.0001
<1.0	632(23.77)	3036(12.61)	744(8.71)	
1.0–3.0	981(47.83)	6839(37.05)	1790(27.06)	
>3.0	405(28.40)	5886(50.35)	2767(64.23)	
Marital status, n (%)				< 0.0001
Coupled	1027(54.97)	9665(65.53)	3362(66.90)	
Single or separated	991(45.03)	6096(34.47)	1939(33.10)	
Alcohol status, n (%)				< 0.0001
Non-drinker	794(35.57)	4731(24.17)	1239(18.53)	
Low to moderate drinker	792(43.00)	7774(53.55)	3180(65.00)	
Heavy drinker	432(21.44)	3256(22.28)	882(16.47)	
Hypertension, n (%)				< 0.0001
No	492(27.79)	8368(56.51)	4468(86.21)	
Yes	1526(72.21)	7393(43.49)	833(13.79)	
Diabetes, n (%)				< 0.0001
No	1097(59.55)	13,073(86.44)	5166(98.10)	
Yes	921(40.45)	2688(13.56)	135(1.90)	
CVD, n (%)				< 0.0001
No	1481(76.23)	14,021(91.07)	5115(97.13)	
Yes	537(23.77)	1740(8.93)	186(2.87)	
Cancer, n (%)				< 0.0001
No	1790(87.79)	14,117(89.07)	4919(92.01)	
Yes	228(12.21)	1644(10.93)	382(7.99)	
LC9 score, mean (SE)	42.93(0.20)	67.11(0.11)	86.72(0.10)	< 0.0001
Diet				< 0.0001
Mean score, mean (SE)	20.72(0.72)	33.89(0.43)	57.65(0.59)	
HEI-2015 score	42.67(0.34)	48.53(0.19)	58.87(0.28)	
Physical activity				< 0.0001
Mean score, mean (SE)	24.10(1.22)	68.95(0.50)	92.69(0.38)	
minutes per week	377.35(22.48)	867.96(21.76)	977.03(27.15)	
Nicotine exposure				< 0.0001
Mean score, mean (SE)	38.63(1.43)	67.07(0.49)	90.74(0.47)	
Sleep health				< 0.0001
Mean score, mean (SE)	61.55(0.93)	82.29(0.27)	92.62(0.28)	
hours per day	6.32(0.05)	6.99(0.01)	7.30(0.02)	
Body mass index				< 0.0001

Table 1 (continued)

Characteristic	LC9 score			*P* value
	0–49	50–79	80–100	
Mean score, mean (SE)	29.63(0.84)	54.30(0.38)	83.59(0.42)	
kg/m2	35.45(0.23)	30.05(0.08)	24.82(0.08)	
Blood lipids				< 0.0001
Mean score, mean (SE)	41.15(0.92)	59.61(0.39)	81.56(0.48)	
non-HDL cholesterol, mg/dL	167.93(1.45)	145.98(0.59)	121.48(0.57)	
Blood glucose				< 0.0001
Mean score, mean (SE)	59.89(0.96)	84.63(0.26)	97.20(0.20)	
HbA1c, %	6.40(0.04)	5.60(0.01)	5.25(0.01)	
Blood pressure				< 0.0001
Mean score, mean (SE)	45.56(0.84)	64.89(0.36)	87.75(0.40)	
Systolic, mmHg	132.39(0.58)	123.75(0.20)	113.31(0.23)	
Diastolic, mmHg	73.77(0.41)	71.60(0.21)	68.12(0.26)	
Psychological health				< 0.0001
Mean score, mean (SE)	65.18(1.03)	88.38(0.28)	96.71(0.17)	
PHQ9 score	7.34(0.21)	3.05(0.05)	1.56(0.03)	

Values are weighted mean (SE) for continuous variables or numbers (weighted %) for categorical variables

Abbreviations: CVD, cardiovascular disease; HbA1c, Hemoglobin A1c; HEI-2015, Healthy Eating Index 2015; LC9, Life's Crucial 9; non-HDL, non-high-density lipoprotein; PHQ-9, Patient Health Questionnaire-9; PIR, poverty income ratio

covariates, a moderate and high CVH was associated with a 33% (HR, 0.67; 95% CI, 0.58–0.78) and 52% (HR, 0.48; 95% CI, 0.38–0.60) lower risk of all-cause mortality. Similarly, those with moderate and high scores were at 49% (HR 0.51; 95% CI 0.40–0.64) and 64% (HR 0.36; 95% CI 0.23–0.56) reduced risk of CVD mortality (Table 2). Kaplan-Meier survival curves demonstrated that there were significant differences in all-cause and CVD mortality among the three CVH groups (log rank $P < 0.0001$), and the survival rate was lowest in the low CVH group and highest in the high CVH group (Fig. 2).

In the RCS analyses of all-cause mortality, the use of AIC statistics indicated that the RCS function with 3 knots (5th, 50th, 95th) was the optimal model (lowest AIC: 31930.93) (Fig. 3A and Additional file 1: Table S2). With regard to CVD mortality, the use of AIC statistics indicated that the RCS function with 3 knots (5th, 50th, 95th) was the optimal model (lowest AIC: 7596.28) (Fig. 3C and Additional file 1: Table S3). For 3 knots RCS, we positioned the 3 knots at the specify percentiles (5th, 50th, 95th) of the data distribution following previous study [23]. Besides, the RCS analyses revealed that within the context of the fully adjusted model (Model 2), there were approximately negative linear dose-response associations of total LC9 score with all-cause and CVD mortality (all P for non-linear > 0.05, Fig. 3B and D). That means the risk of all-cause and CVD mortality decreased linearly with increase in LC9 score. Particularly, participants with the lower LC9 scores seem to benefit more from a small improvement of LC9 scores.

Subgroup and sensitivity analyses

The stratified analyses revealed significant interactions between age, education level, family income for all-cause mortality, and age for CVD mortality, and did not show the interaction between other variables for mortality (Tables 3 and 4). Across the same level of CVH, older adults have a higher risk of all-cause and CVD mortality compared to younger adults, while higher education and income group experienced lower all-cause mortality than lower education and income group, respectively. This suggests that older adults and those with lower education and income may be more sensitive to changes in LC9, indicating that they may benefit more from interventions aimed at improving the 9 indicators of LC9.

Besides, the results were robust in sensitivity analyses when excluding deaths within two years of follow-up (1,671 participants were excluded, resulting in 21,409 participants being included in this analysis) (Additional file 1: Table S4), excluding participants with hypertension, diabetes, CVD and cancer (11,121 participants were excluded, resulting in 11,959 participants being included in this analysis) (Additional file 1: Table S5), excluding participants treated with antiplatelet medications, angiotensin-converting enzyme inhibitors, beta-blockers, statins, or glucocorticoids (6,483 participants were excluded, resulting in 16,597 participants being included in this analysis) (Additional file 1: Table S6), multivariate single imputation on missing values of covariates (2,657 participants were included, resulting in 25,737 participants being included in this analysis) (Additional file 1: Table S7), and using anxiety to measure psychological health (10,690 participants were included in this analysis) (Additional file 1: Table S8).

Table 2 Association of the life's crucial 9 score with all-cause and cardiovascular disease mortality in the united States National health and nutrition examination survey 2005–2018 cohort

	Crude model		Model 1		Model 2	
All-cause mortality						
	HR (95% CI)	*P* value	HR (95% CI)	*P* value	HR (95% CI)	*P* value
Low (0–49) (*n* = 2018)	1 (reference)		1 (reference)		1 (reference)	
Moderate (50–79) (*n* = 15761)	0.46(0.39,0.53)	< 0.0001	0.47(0.41,0.55)	< 0.0001	0.67(0.58,0.78)	< 0.0001
High (80–100) (*n* = 5301)	0.17(0.14,0.20)	< 0.0001	0.26(0.21,0.33)	< 0.0001	0.48(0.38,0.60)	< 0.0001
CVD mortality						
	HR (95% CI)	*P* value	HR (95% CI)	*P* value	HR (95% CI)	*P* value
Low (0–49) (*n* = 2018)	1 (reference)		1 (reference)		1 (reference)	
Moderate (50–79) (*n* = 15761)	0.34(0.27,0.42)	< 0.0001	0.32(0.26,0.40)	< 0.0001	0.51(0.40,0.64)	< 0.0001
High (80–100) (*n* = 5301)	0.11(0.07,0.16)	< 0.0001	0.16(0.11,0.24)	< 0.0001	0.36(0.23,0.56)	< 0.0001

Model 1: adjusted for age, sex, and ethnicity

Model 2: Model 1 + education level, family income, marital status, alcohol status, hypertension, diabetes, CVD and cancer

Abbreviations: CI, confidence intervals; CVD, cardiovascular disease; HR, hazards ratio

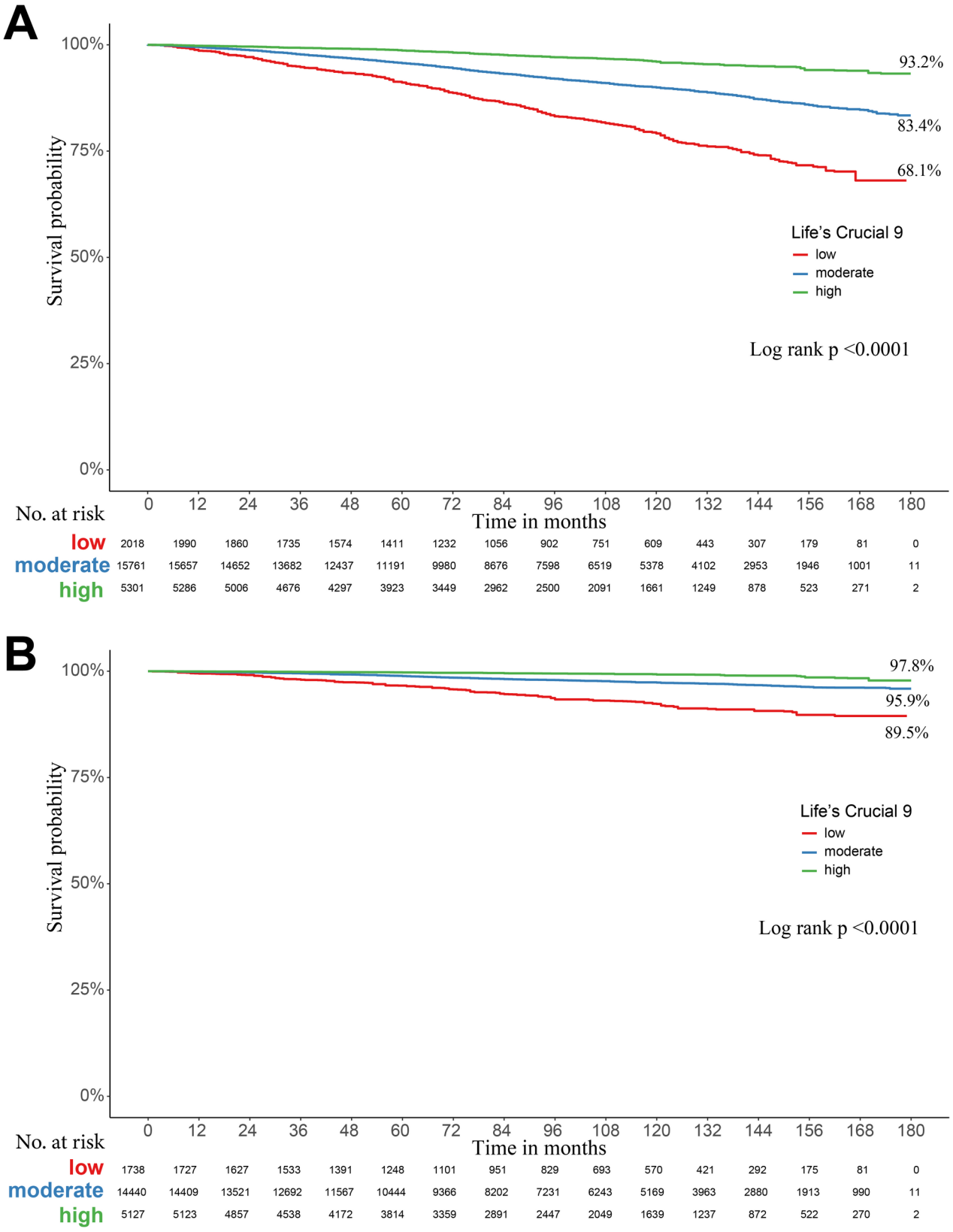

Fig. 2 Kaplan-Meier curves of all-cause (**A**) and cardiovascular disease (**B**) mortality by Life's Crucial 9 metrics in the United States from National Health and Nutrition Examination Survey cohort study 2005–2018

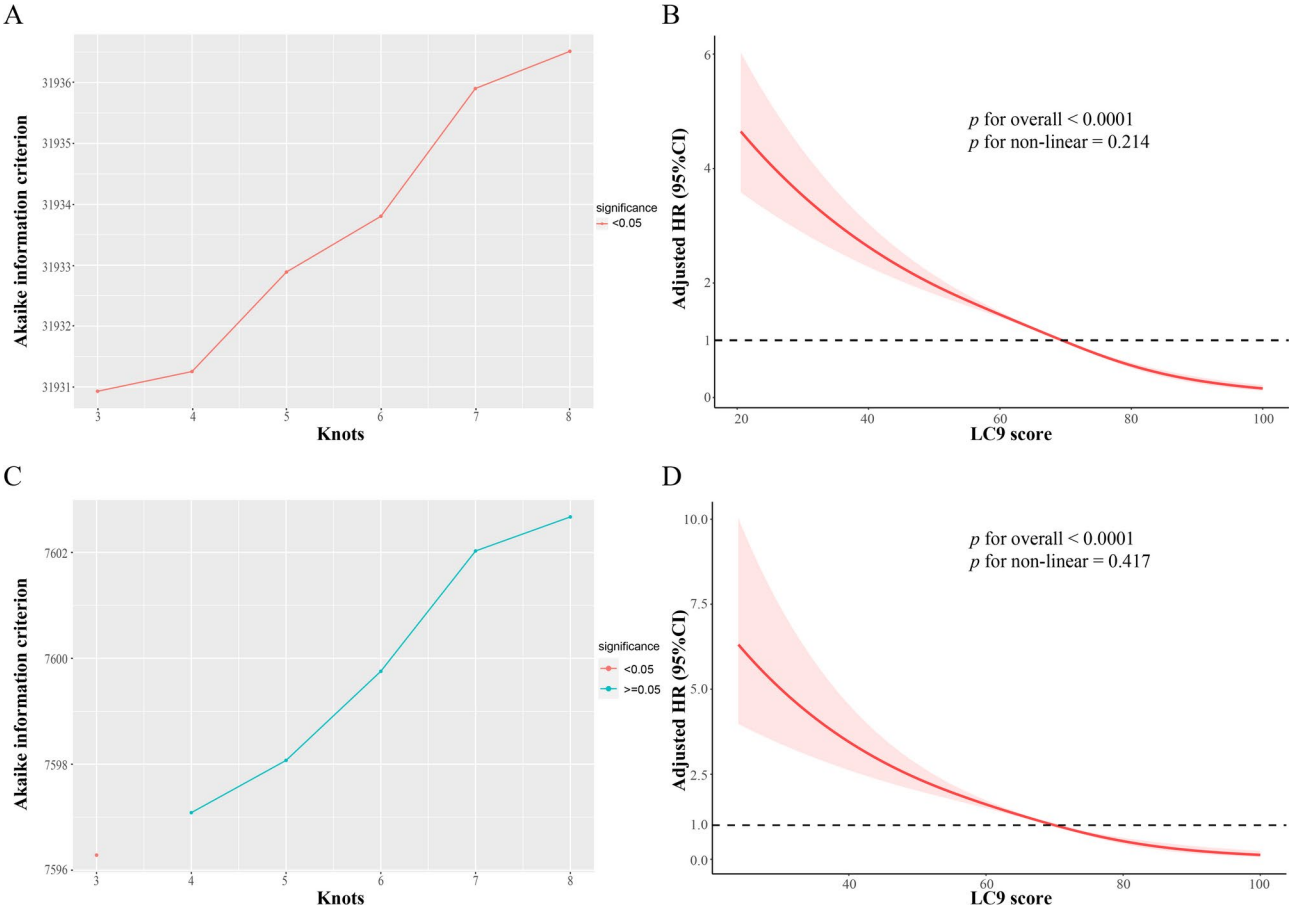

Fig. 3 The multivariable adjusted restricted cubic spline model for association of Life's Crucial 9 score with all-cause (**A**-**B**) and cardiovascular disease (**C**-**D**) mortality in the United States from National Health and Nutrition Examination Survey cohort study 2005–2018. A The restricted cubic spline model with 3 knots showed the lowest Akaike information criterion statistics; B Association of Life's Crucial 9 score with all-cause mortality. P for non-linear = 0.214. C The restricted cubic spline model with 3 knots showed the lowest Akaike information criterion statistics; D Association of Life's Crucial 9 score with cardiovascular disease mortality. P for non-linear = 0.417. Abbreviation: HR, hazard ratios; LC9, Life's Crucial 9

PAFs of LC9 to all-cause and CVD mortality

Figure 4 shows that the adjusted PAF of high (≥ 80 points) vs. moderate or low CVH score (< 80 points) with all-cause mortality was 46.0%, and the 9 components were ranked in the relative order of higher to lower fractions as follows: non-HDL cholesterol (29.3%), BMI (24.0%), sleep health (11.6%), diet (9.5%), blood pressure (6.3%), psychological health (5.3%), nicotine exposure (3.0%), physical activity (1.4%), blood glucose (0.4%). In addition, the adjusted PAF of high (≥ 80 points) vs. moderate or low CVH score (< 80 points) with CVD mortality was 75.8%, fractions of the 9 components from higher to lower were: nicotine exposure (46.7%), psychological health (44.6%), non-HDL cholesterol (42.0%), BMI (34.8%), diet (33.2%), sleep health (26.9%), physical activity (21.4%), blood glucose (16.0%), blood pressure (12.5%).

Incremental predictive value of psychological health

Figure 5 displays the accuracies of the Cox models of LE8 and LC9 score in predicting all-cause and CVD mortality. After adjusting for covariates, the LC9 model of predicting all-cause mortality yielded an AUC of 0.883, while the LE8 model yielded an AUC of 0.859 (Fig. 5A). Comparison of the ROC curves of the models suggested that the LC9 model significantly outperformed the LE8 model in predicting all-cause mortality ($P = 0.048$). Besides, in predicting CVD mortality, the AUC value for the LC9 was 0.918, whereas the AUC value for the LE8 was 0.889 ($P = 0.052$) (Fig. 5B). Besides, the incremental predictive values of the PHQ-9 score and depression score for all-cause and CVD mortality are summarized in Table 5. In all the five different methods, the reclassification power significantly improved for all-cause and CVD mortality after the inclusion of the PHQ-9 score or depression score in the basic model.

Discussion

In this nationally representative cross-sectional study of US adults, our findings showed that all-cause and CVD mortality was significantly decreased in high and

Table 3 Variables-stratified analyses for the association the life's crucial 9 score with all-cause mortality in the united States National health and nutrition examination survey 2005–2018 cohort

Characteristic	LC9 score			*P* interaction
	Low (0–49)	Moderate (50–79)	High (80–100)	
Age				< 0.001
20–39 (*n* = 7594)	1 (reference)	0.81(0.37, 1.73)	0.40(0.14,0.68)	
40–59 (*n* = 7819)	1 (reference)	0.66(0.46,0.94)	0.39(0.20,0.77)	
≥ 60 (*n* = 7667)	1 (reference)	0.86(0.73,0.97)	0.70(0.55,0.90)	
Sex		0.169		
Female (*n* = 11724)	1 (reference)	0.76(0.60,0.96)	0.46(0.33,0.65)	
Male (*n* = 11356)	1 (reference)	0.60(0.47,0.77)	0.48(0.34,0.68)	
Race or ethnicity		0.450		
Non-Hispanic white (*n* = 10848)	1 (reference)	0.64(0.54,0.76)	0.46(0.36,0.59)	
Non-Hispanic black (*n* = 4632)	1 (reference)	0.79(0.64,0.99)	0.34(0.18,0.61)	
Mexican American (*n* = 3378)	1 (reference)	0.75(0.49,1.15)	1.22(0.59,2.56)	
Others (*n* = 4222)	1 (reference)	0.85(0.47,1.54)	0.66(0.26,0.94)	
Education		0.019		
Less than high school (*n* = 4938)	1 (reference)	0.66(0.55,0.79)	0.49(0.33,0.73)	
High school or equivalent (*n* = 5301)	1 (reference)	0.91(0.68,1.23)	0.66(0.40,1.07)	
College or above (*n* = 12841)	1 (reference)	0.54(0.41,0.70)	0.41(0.29,0.58)	
Marital status	0.391			
Married (*n* = 14054)	1 (reference)	0.63(0.49,0.81)	0.49(0.34,0.70)	
Single or separated (*n* = 9026)	1 (reference)	0.72(0.59,0.89)	0.46(0.33,0.66)	
PIR		0.002		
< 1 (*n* = 7667)	1 (reference)	0.89(0.68,0.95)	0.69(0.39,0.89)	
1–3 (*n* = 7667)	1 (reference)	0.76(0.64,0.90)	0.49(0.37,0.66)	
> 3 (*n* = 7667)	1 (reference)	0.40(0.28,0.58)	0.31(0.20,0.50)	
Alcohol status				0.267
Non-drinker (*n* = 6764)	1 (reference)	0.76(0.62,0.93)	0.54(0.39,0.76)	
Drinker (*n* = 16316)	1 (reference)	0.58(0.46,0.73)	0.42(0.30,0.58)	
Hypertension				0.172
No (*n* = 13328)	1 (reference)	0.84(0.71,1.08)	0.70(0.45,0.89)	
Yes (*n* = 9752)	1 (reference)	0.60(0.52,0.71)	0.48(0.36,0.64)	
Diabetes				

Table 3 (continued)

Characteristic	LC9 score			*P* interaction
	Low (0–49)	Moderate (50–79)	High (80–100)	
No	1 (reference)	0.71(0.56,0.89)	0.51(0.39,0.67)	0.893
(*n* = 19336)				
Yes	1 (reference)	0.64(0.50,0.81)	0.41(0.17,0.96)	
(*n* = 3744)				
CVD				0.329
No	1 (reference)	0.62(0.51,0.76)	0.45(0.33,0.61)	
(*n* = 20617)				
Yes	1 (reference)	0.78(0.62,0.98)	0.57(0.39,0.82)	
(*n* = 2463)				
Cancer				0.313
No	1 (reference)	0.68(0.58,0.79)	0.45(0.34,0.58)	
(*n* = 20826)				
Yes	1 (reference)	0.66(0.48,0.89)	0.57(0.37,0.90)	
(*n* = 2254)				

Values are weighted hazard ratio (95% confidence interval)

Model: adjusted for age, sex, ethnicity, education level, marital status, family income, alcohol status, hypertension, diabetes, CVD and cancer, with excluding the stratifying factors

Abbreviations: CVD, cardiovascular disease; LC9, Life's Crucial 9; PIR, poverty-to-income ratio

moderate CVH group compared to low CVH group. There were approximately negative linear dose-response relationships of total LC9 score with all-cause and CVD mortality. Through our subgroup analysis, the correlation between LC9 and mortality was found to be stronger among older adults and those with lower education and income. Furthermore, Our PAF analysis demonstrates that 46.0% of all-cause mortality and 75.8% of CVD mortality in low and moderate CVH group could be averted by reaching the level of high CVH.

As an updated algorithm introduced by the AHA in 2022, the LE8 score is a comprehensive and sensitive indicator to assess individuals' CVH [5]. Evidence has consistently shown that LE8 score is inversely correlated with the risks of various non-communicable chronic diseases, including coronary heart disease [6], diabetes [24], metabolic associated fatty liver disease [25], depression [19], and other common NCDs [7]. Moreover, previous multiple studies with different populations have indicated that achieving a high LE8 score can significantly reduce mortality [9, 26, 27, 28, 29]. By comprehensively combining four modifiable health behaviors (diet, physical activity, nicotine exposure, sleep health) and four health factors (BMI, non-HDL cholesterol, blood glucose, blood pressure), the LE8 score is considered as an ideal cardiovascular health metric. Nonetheless, the current LE8 scoring system does not encompass psychological health, which the AHA has characterized as "a metric that plays a foundational role in achieving optimal and equitable CVH in the population" [5]. Decades of research have repeatedly underscored the pivotal role of psychological health factors in preserving and improving CVH. Positive psychological health factors such as optimism, happiness, mindfulness, and sense of purpose are associated with more favorable CVH [30, 31, 32, 33]; Conversely, negative psychological characteristics (depression, anxiety, pessimism, and stress) are linked to poor CVH [34, 35, 36, 37]. Consequently, there is a compelling rationale for the integration of psychological health into the CVH scoring algorithm.

The multidimensionality of psychological health prompted us to explore which psychological indicator may be of the greatest significance for influencing CVH. Based on their comprehensive review of the literature, the US Preventive Services Task Force found that depression and anxiety had strong negative consequences on CVH [12]. In the NHANES, depression status was evaluated using the Depression Questionnaire since 2005, whereas the Anxiety Questionnaire was limited to the NHANES 2007–2012 cycles [38, 39]. From this point, depression was regarded as a more reliable psychological phenotype measured in NHANES. In our study, psychological health was assessed by PHQ-9, which has been extensively validated in terms of the severity of depression, showing a sensitivity of 88% and a specificity of 85% [40]. Based on LC9 scoring algorithm which integrates psychological health and other eight metrics (diet, physical activity, nicotine exposure, sleep health, BMI, non-HDL cholesterol, blood glucose, blood pressure) in LE8, we found that there were approximately linear inverse dose-response associations of increased LC9 score with reduced risk of all-cause and CVD mortality. Intriguingly, the inverse trend was more pronounced at lower LC9 scores, suggesting that individuals with the lower LC9 score may benefit more from a small improvement in the LC9 score. For such populations, if they cannot

Table 4 Variables-stratified analyses for the association the life's crucial 9 score with cardiovascular disease mortality in the united States National health and nutrition examination survey 2005–2018 cohort

Characteristic	LC9 score			*P* interaction
	Low (0–49)	Moderate (50–79)	High (80–100)	
Age				< 0.001
20–39 (*n* = 7594)	1 (reference)	0.15(0.05,0.47)	0.10(0.01,0.87)	
40–59 (*n* = 7819)	1 (reference)	0.40(0.23,0.72)	0.03(0.01,0.08)	
≥ 60 (*n* = 7667)	1 (reference)	0.78(0.57,0.94)	0.71(0.44,0.90)	
Sex		0.538		
Female (*n* = 11724)	1 (reference)	0.66(0.44,0.99)	0.45(0.21,0.97)	
Male (*n* = 11356)	1 (reference)	0.42(0.28,0.62)	0.31(0.18,0.53)	
Race or ethnicity		0.971		
Non-Hispanic white (*n* = 10848)	1 (reference)	0.47(0.36,0.61)	0.33(0.21,0.53)	
Non-Hispanic black (*n* = 4632)	1 (reference)	0.58(0.38,0.88)	0.42(0.18,0.96)	
Mexican American (*n* = 3378)	1 (reference)	0.78(0.35,1.73)	0.60(0.10,3.66)	
Others (*n* = 4222)	1 (reference)	0.62(0.16, 2.43)	0.18(0.03,0.88)	
Education		0.650		
Less than high school (*n* = 4938)	1 (reference)	0.52(0.30,0.88)	0.42(0.19,0.97)	
High school or equivalent (*n* = 5301)	1 (reference)	0.60(0.38,0.92)	0.34(0.13,0.88)	
College or above (*n* = 12841)	1 (reference)	0.45(0.28,0.73)	0.35(0.18,0.67)	
Marital status	0.602			
Married (*n* = 14054)	1 (reference)	0.43(0.29,0.64)	0.32(0.17,0.58)	
Single or separated (*n* = 9026)	1 (reference)	0.61(0.42,0.87)	0.42(0.23,0.77)	
PIR		0.425		
< 1 (*n* = 7667)	1 (reference)	0.70(0.43,1.12)	0.39(0.14,0.70)	
1–3 (*n* = 7667)	1 (reference)	0.55(0.41,0.75)	0.36(0.20,0.64)	
> 3 (*n* = 7667)	1 (reference)	0.29(0.15,0.53)	0.23(0.10,0.53)	
Alcohol status				0.185
Non-drinker (*n* = 6764)	1 (reference)	0.66(0.46,0.95)	0.47(0.27,0.82)	
Drinker (*n* = 16316)	1 (reference)	0.39(0.27,0.58)	0.29(0.16,0.52)	
Hypertension				0.847
No (*n* = 13328)	1 (reference)	0.66(0.33,1.31)	0.51(0.21,0.88)	
Yes (*n* = 9752)	1 (reference)	0.49(0.38,0.62)	0.33(0.20,0.55)	
Diabetes				

Table 4 (continued)

Characteristic	LC9 score			*P* interaction
	Low (0–49)	Moderate (50–79)	High (80–100)	
No	1 (reference)	0.54(0.35,0.83)	0.39(0.23,0.67)	0.786
(*n* = 19336)				
Yes	1 (reference)	0.49(0.34,0.71)	0.25(0.09,0.74)	
(*n* = 3744)				
CVD				0.892
No	1 (reference)	0.43(0.29,0.63)	0.28(0.16,0.49)	
(*n* = 20617)				
Yes	1 (reference)	0.63(0.41,0.97)	0.55(0.29,1.05)	
(*n* = 2463)				
Cancer				0.865
No	1 (reference)	0.49(0.38,0.63)	0.35(0.22,0.57)	
(*n* = 20826)				
Yes	1 (reference)	0.58(0.27,1.27)	0.39(0.13,0.63)	
(*n* = 2254)				

Values are weighted hazard ratio (95% confidence interval)

Model: adjusted for age, sex, ethnicity, education level, marital status, family income, alcohol status, hypertension, diabetes, CVD and cancer, with excluding the stratifying factors

Abbreviations: CVD, cardiovascular disease; LC9, Life's Crucial 9; PIR, poverty-to-income ratio

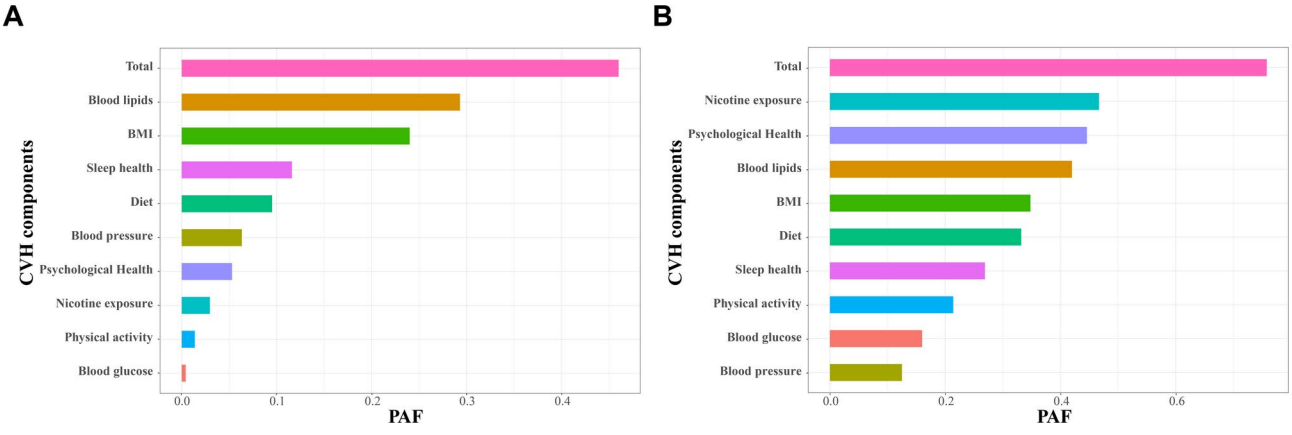

Fig. 4 Populations attributable fractions of all-cause (**A**) and cardiovascular disease (**B**) mortality for each Life's Crucial 9 component in the United States from National Health and Nutrition Examination Survey cohort study 2005–2018. Abbreviation: BMI, body mass index; CVH, cardiovascular health; PAF, populations attributable fractions

achieve a higher score in some metrics of the LC9 scoring algorithm, better performance on the other metrics can also reduce the risk of death. For example, if a busy working environment discourages someone from achieving adequate physical activity and sufficient sleep duration, a balanced diet or good psychological health can still confer a survival benefit for them.

Presenting the contributions of individual metrics for all-cause and CVD mortality in one study population has significant implications, which has been quite rare in previous studies. In our findings, the PAFs for mortality of the nine components in LC9 scoring algorithm could be compared and ranked. Among these nine modifiable factors, non-HDL cholesterol was the largest important individual contributor to all-cause mortality and the third important individual contributor to CVD morality. Non-HDL cholesterol represented the sum of all atherogenic lipoprotein, including intermediate-density lipoprotein cholesterol, low-density lipoprotein cholesterol, very low-density lipoprotein cholesterol, chylomicron remnants, and lipoprotein (a) [41]. Evidence from Mendelian randomization studies has firmly established the association between non-HDL cholesterol and the risk of coronary atherosclerosis and coronary artery disease, indicating its predictive capacity that extends beyond traditional genetic risk factors for low-density lipoprotein cholesterol [42, 43]. In line, elevated non-HDL cholesterol is a causal factor for atherosclerotic cardiovascular disease morbidity and mortality [44, 45]. Our study underscored the strong correlation between non-HDL cholesterol and

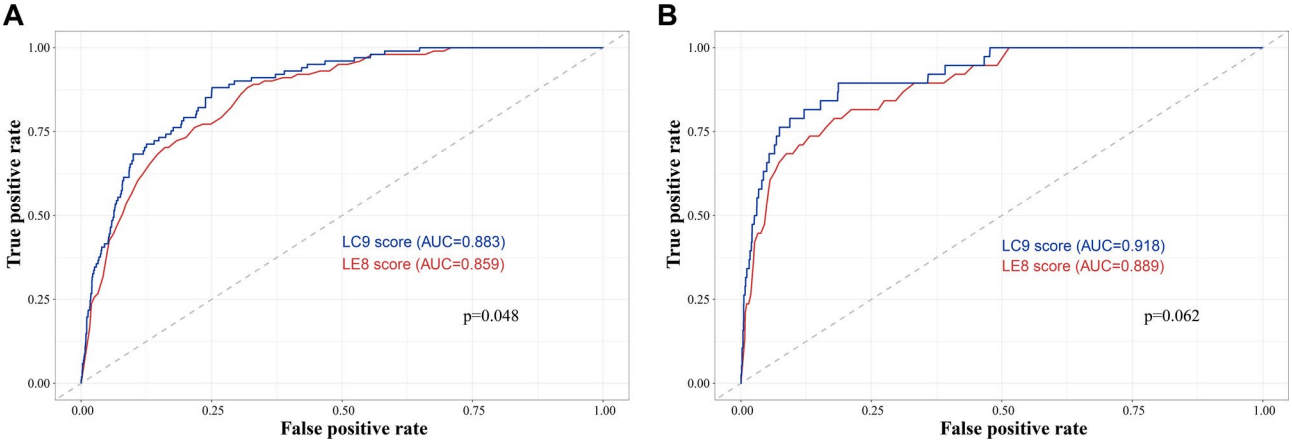

Fig. 5 The Life's Essential 8 and Life's Crucial 9 score Cox model receiver operating characteristic curves for predicting all-cause (**A**) and cardiovascular disease (**B**) mortality in the United States from National Health and Nutrition Examination Survey cohort study 2005–2018. Abbreviation: AUC, area-under-the-curve; LC9, Life's Crucial 9; LE8, Life's Essential 8

Table 5 Prognostic value of psychological health in addition to life's essential 8 for all-cause and cardiovascular disease mortality in the united States National health and nutrition examination survey 2005–2018 cohort

	KM	IPW	SmoothIPW	SEM	Combined
All-cause mortality					
Basic model	reference	reference	reference	reference	reference
Basic model + PHQ-9 score	0.396(0.220,0.617)	0.396(0.220,0.617)	0.396(0.220,0.617)	0.204(0.042,0.442)	0.396(0.220,0.617)
Basic model + depression score	0.264(0.133,0.351)	0.264(0.133,0.351)	0.264(0.133,0.351)	0.129(0.057,0.205)	0.264(0.133,0.351)
CVD mortality					
Basic model	reference	reference	reference	reference	reference
Basic model + PHQ-9 score	0.527(0.244,0.766)	0.527(0.244,0.766)	0.528(0.244,0.766)	0.224(0.057,0.449)	0.467(0.244,0.704)
Basic model + depression score	0.287(0.197,0.605)	0.287(0.197,0.605)	0.287(0.197,0.605)	0.138(0.023,0.208)	0.255(0.217,0.553)

The basic model was adjusted for Life's Essential 8, age, sex, ethnicity, education level, family income, marital status, alcohol status, hypertension, diabetes, CVD and cancer. The result was presented as net reclassification improvement (NRI) with 95% confidence intervals using five different estimators: Kaplan-Meier estimator (KM), Inverse probability weighted estimator (IPW), Smooth inverse probability weighted estimator (SmoothIPW), Semi-parametric estimator (SEM), and Combined estimator (Combined)

Abbreviations: CVD, cardiovascular disease; PHQ-9, Patient Health Questionnaire-9

risk of mortality, and highlighted non-HDL cholesterol as a vital target for intervention to reduce all-cause and CVD mortality.

We also found that BMI was the second important individual contributor to all-cause mortality and the third important individual contributor to CVD mortality. The latest data from the GBD 2021 showed that the age-standardized global disability-adjusted life-years rate attributed to high BMI increased by 15.7% (1.8% yearly) from 2000 to 2021 [46]. In an umbrella review and meta-analysis involving 501 cohort studies, Kim et al. [47] found that per 5 kg/m2 increase in BMI was led to a 5% (95% CI 2–7%) higher risk of all-cause mortality and a 49% (95% CI 45–53%) higher risk of CVD mortality. Our findings reinforce the above study that increased BMI was associated with a higher risk of all-cause and CVD mortality. However, we suppose that the quantification and scoring of BMI in the LC9 scoring algorithm need to be further optimized. According to WHO and NIH guidelines, BMI can be categorized into six groups: underweight (BMI < 18.5 kg/m2), normal weight (BMI 18.5–24.9 kg/m2), overweight (BMI 25.0–29.9 kg/m2), obesity grade I (BMI 30.0–34.9 kg/m2), obesity grade II (BMI 35.0–39.9 kg/m2), and obesity grade III (BMI ≥ 40.0 kg/m2). In comparison, the points level of BMI in the LC9 scoring algorithm was divided into five grades: 100 points (BMI < 25.0 kg/m2), 70 points (BMI 25.0–29.9 kg/m2), 30 points (BMI 30.0–34.9 kg/m2), 15 points (BMI 35.0–39.9 kg/m2), and 0 points (BMI ≥ 40.0 kg/m2). Indeed, the J-shaped association of BMI with all-cause and CVD mortality has been well-documented [48, 49], and underweight (vs. normal weight) was correlated with increased all-cause and CVD mortality. These findings suggest that the AHA should separate the group with 100 points (BMI < 25.0 kg/m2) into underweight (BMI < 18.5 kg/m2) and normal weight (BMI 18.5–24.9 kg/m2) categories.

As a newly added metric in the LE8 scoring algorithm, ideal sleep duration (7 to 9 h a day) was widely accepted to be related to reduced all-cause mortality rates [50, 51]. In our study, we found that inappropriate sleep

duration was the third important individual contributor to all-cause mortality, which reinforced the above findings. Nevertheless, sleep health is multidimensional and comprises many aspects including duration, quality, timing, regularity, efficiency, etc. Previous studies defined sleep health as early chronotype; sleep 7 to 8 h per day; reported never or rarely insomnia symptoms; no self-reported snoring; and no frequent daytime sleepiness [52, 53]. Future studies are needed to demonstrate the relationship between other sleep metrics and CVH.

Our analysis reveals that nicotine exposure (PAF: 46.7%) was the primary risk factor for CVD mortality. It is estimated that cigarette smoking causes nearly 530,000 deaths in the US every year, primarily from neoplastic, cardiovascular, and respiratory diseases [54]. Several studies have proven that smoking cessation has considerable benefits on CVH. Based on the large-scale prospective cohort study of the National Health Interview Survey, Thomson et al. [55] discovered that 34.7% of CVD mortality could have been avoided if all ever smokers quit smoking. When comparing those who quit smoking before age 35 years with never smokers, no significant variations were observed in CVD mortality. Our study has also demonstrated the viewpoint that quitting smoking at an early age allows for the avoidance of tobacco-related CVD mortality.

As one of the reliable psychological phenotypes measured in NHANES, depression (PAF: 44.6%) was the second important individual contributor to CVD mortality. Our findings about association between depression and CVD mortality risk are consistent with previous study results [56, 57, 58]. A prospective cohort study in the United States reported that the CVD mortality risk of participants with mild and moderate to severe depression was increased by 49% and 79%, respectively [56]. Similarly, a prospective study using two large cohorts in China reported a similar association between depression and CVD mortality [57]. Several mechanisms could explain this association. On the one hand, depression could lead to unhealthy lifestyles such as sedentary behavior, cigarette smoking, disordered eating behaviors, and weight gain, which are associated with an increased risk of CVD deaths [59, 60, 61, 62]. On the other hand, low socioeconomic status including less education, being unmarried, not currently working, and lack of insurance are correlated with depression and may play a contributing role in the link between depression and CVD mortality risk [63, 64].

In our study, we used the NRI method to assess the prognostic value of psychological health in addition to LE8 for all-cause and CVD mortality via the R package 'survNRI'. In all the five different methods, the reclassification power significantly improved after the inclusion of the PHQ-9 score or depression score in the basic model (LE8 and other covariates). This result is inconsistent with a previous study by Ge et al. [65]. In their analysis of NHANES 2007–2018 cycles, they found that in addition to the LE8 score, the depression score provided a small improvement in predicting all-cause and CVD mortality. One of the possibilities that could explain this discrepancy is the different inclusion of covariates. Age, sex, ethnicity, education level, family income, and marital status were included as covariates in their study. While in our study, alcohol status, hypertension, diabetes, CVD, and cancer were included as additional covariates. Besides, our study included Participants from NHANES 2005–2018, which was different from their study (2007–2018).

The strengths of our study include the use of large-scale nationally representative data, the new LC9 scoring algorithm for evaluating the relations of CVH with both all-cause and CVD mortality, and comparing the contribution of 9 components of LC9 to mortality. This study also has several limitations. First, the assessment of health behavior indicators, such as physical activity and sleep duration, was based on self-report questionnaires rather than instrument measurements, which are susceptible to recall bias. Second, data on CVH metrics were only obtained at baseline. Thus, we were unable to consider the impact of long-term variations in these CVH metrics over the course of follow-up. Further studies are needed to determine the relationship between changes in CVH metrics and health outcomes. Third, the current conclusion is based on US adults, which may limit the generalizability and applicability to other populations. Fourth, the determination of psychological health is based on multiple factors, so using depression exclusively might contribute significant bias in the assessment of psychological health. Finally, because of the observational study design, causality could not be established.

Conclusion

In conclusion, in this nationally representative sample of US adults, our study revealed that preserving a better CVH, defined as a higher LC9 score, was related to a significant reduction in all-cause and CVD mortality. Elevated non-HDL cholesterol level, high BMI, and poor sleep quality were the three major contributors to all-cause mortality, whereas nicotine exposure, unhealthy psychology, and elevated non-HDL cholesterol level were the three significant ones to CVD mortality. The findings suggested that implementing aggressive primordial preventive strategies to optimize CVH factors, especially aiming at health behaviors and risk factors with high PAFs, will improve CVH and reduce mortality risk.

Abbreviations

AHA	American Heart Association
AIC	Akaike information criterion
AUC	Area-under-the-curve

BMI	Body mass index
CI	Confidence interval
CVD	Cardiovascular disease
CVH	Cardiovascular health
GBD	Global Burden of Disease
HbA1c	Hemoglobin A1c
HEI-2015	Healthy Eating Index 2015
HR	Hazard ratio
LC9	Life's Crucial 9
LE8	Life's Essential 8
NCDs	Non-CVD noncommunicable diseases
NDI	National Death Index
NHANES	National Health and Nutrition Examination Survey
non-HDL	Non-high-density lipoprotein
NRI	Net Reclassification Improvement
PAFs	Population attributable fractions
PHQ-9	Patient Health Questionnaire-9
RCS	Restricted cubic spline
ROC	Receiver operating characteristic
SE	Standard errors
US	United States

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13690-025-01607-2.

Supplementary Material 1

Acknowledgements

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Author contributions

DYT, QX, and JS designed the study and conducted the data analysis. DYT and CQM drafted the manuscript. CQM and PL proposed critical revisions to the manuscript. All authors read and approved the final manuscript.

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Data availability

The National Health and Nutrition Examination Survey dataset is publicly available at the National Center for Health Statistics of the Center for Disease Control and Prevention (https://wwwn.cdc.gov/nchs/nhanes/Default.aspx).

Declarations

Ethics approval and consent to participate

The NHANES was approved by the National Center for Health Statistics Research Ethics Review Board, and all participants provided written informed consent.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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