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Comparative Discrimination of Life's Simple 7, Life's Essential 8, and Life's Crucial 9: Evaluating the impact of added complexity on mortality prediction

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Abstract

Background Cardiovascular health (CVH) is a key determinant of mortality, but the comparative effectiveness of different CVH metrics remains uncertain. Life's Simple 7 (LS7) evaluates seven domains: smoking, body mass index, physical activity, total cholesterol, blood pressure, fasting glucose, and diet. Life's Essential 8 (LE8) adds sleep health, while Life's Crucial 9 (LC9) further includes mental health. This study aimed to assess whether the additional components in LE8 and LC9 enhance mortality prediction compared to LS7.

Methods Data from 22,382 participants in the NHANES 2005–2018 were analyzed. Cox proportional hazards regression models were used to evaluate the associations between the scores of these metrics and all-cause, cardio-cerebrovascular disease (CCD), and CVD mortality. The predictive performance of each metric was assessed via receiver operating characteristic (ROC) curves and area under the curve (AUC) values.

Results The participants had a mean age of 45.23 ± 0.23 years, and 51.53% were female. During a median follow-up of 7.75 (4.42–11.08) years, there were 1,483 all-cause deaths, 405 CCD deaths, and 337 CVD deaths. Compared with participants with LS7 scores ≤ 4, those with scores ≥ 11 had a 65% (HR = 0.35 [0.25–0.50]) lower risk of all-cause mortality, a 66% (HR = 0.34 [0.16–0.73]) lower risk of CCD mortality, and a 61% (HR = 0.39 [0.18–0.85]) lower risk of CVD mortality. Similar trends were observed for LE8 and LC9. The AUC for LS7 (0.68 [0.66–0.70]) was slightly greater than that for LE8 (0.67 [0.65–0.69], $P = 0.007$) and LC9 (0.67 [0.65–0.69], $P = 0.019$) in predicting all-cause mortality at 5 years; however, the overall predictive performance was nearly identical across all three metrics. Furthermore, the addition of LS7 (AUC = 0.84 [0.82–0.86], $P < 0.001$), LE8 (AUC = 0.84 [0.82–0.86], $P < 0.001$), and LC9 (AUC = 0.84 [0.83–0.86], $P < 0.001$) to the baseline model (AUC = 0.83 [0.82–0.85]) significantly improved all-cause mortality predictions at 5 years; however, the actual gains in predictive performance were marginal.

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Conclusions LS7, LE8, and LC9 all predict mortality effectively. Given its simpler scoring and fewer components, LS7 demonstrates comparable predictive performance to LE8 and LC9, making it a more practical tool for clinical and public health applications.

Keywords Life's Simple 7, Life's Essential 8, Life's Crucial 9, Mortality, NHANES

Background

Cardiovascular disease (CVD) exerts a substantial burden on public health, affecting approximately 10% of adults and accounting for nearly 25% of annual deaths in the U.S. [1]. By 2019, the number of CVD-related deaths had risen to 18.6 million, representing a substantial increase of over 50% over the preceding three decades [2]. Part of this rise can be attributed to the aging of the population, as the global trend of rapid population aging is likely to significantly increase the incidence of CVD in the coming decades [3]. By 2050, the number of individuals aged 65 and above is projected to reach 366 million, accounting for 26.1% of the global population [4]. The increasing incidence of CVD places considerable strain on global health care systems. Countries with rapidly aging populations must prioritize cardiovascular health (CVH) in public health strategies.

In 2010, the American Heart Association (AHA) introduced Life's Simple 7 (LS7) score for assessing CVH, which takes into account seven key modifiable risk factors, including smoking status, body mass index (BMI), physical activity, total cholesterol (TC), blood pressure, fasting blood glucose (FBG), and diet [5]. The LS7 score ranges from 0 to 14, with higher scores indicating better CVH [5]. Recognizing the growing body of evidence linking sleep health with CVH, the Life's Essential 8 (LE8) score includes sleep duration as a key component alongside the original seven metrics [6]. By quantifying CVH on a scale of 0 to 100 and factoring in medication use, the LE8 score provides a clearer, more accurate assessment for CVH [6]. Building on LE8, Life's Crucial 9 (LC9) further incorporates psychological well-being as a crucial component of CVH [7].

Overall, research has demonstrated that corresponding healthy lifestyle habits, such as regular exercise, a nutritious diet, avoiding tobacco, and maintaining a healthy weight, can significantly reduce the risk of major chronic diseases. A large cohort study involving more than 339,000 adults examined how a healthy lifestyle can protect against CVD and diabetes and revealed that participants who adhered to multiple LS7 components had significantly lower rates of new-onset CVD than did those with poor adherence to these components [8]. Similarly, a recent meta-analysis concluded that addressing multiple lifestyle factors simultaneously—such as smoking status, alcohol consumption, physical activity, diet, and obesity—was more effective in reducing the risk of chronic diseases than focusing on individual behaviors [9]. Zhang et al. reported that higher levels of CVH, as defined by Life's Essential 8 metrics, were significantly associated with a lower risk of both all-cause mortality and CVD mortality [10].

Several studies have provided compelling evidence that adhering to a greater number of ideal CVH metrics is associated with a significant reduction in CVD and all-cause mortality [11]. Although an intermediate CVH profile is associated with significant cardiovascular protection and a reduced risk of CVD and all-cause mortality [12], this observation suggests that further refinement in CVH assessment could enhance risk stratification. In this context, metrics such as LE8 and LC9—which incorporate additional components such as sleep and mental health—have been developed to provide a more comprehensive evaluation of CVH, potentially offering greater precision and responsiveness in capturing subtle changes [13]. However, previous research has suggested that compared with LE8, LC9 does not offer a meaningful improvement in predictive value, and its overall utility remains uncertain [7].

The potential of these updated metrics, particularly LE8 and LC9, to improve mortality risk prediction has not been thoroughly validated. Moreover, a direct comparison of the predictive performance of LS7, LE8, and LC9 has been largely unexplored. The aim of this study was to address this gap by examining the relationships between these CVH scores and all-cause, cardio-cerebrovascular disease (CCD), and CVD mortality risk, as well as their relative predictive performance in a large cohort of adults from the National Health and Nutrition Examination Survey (NHANES).

Methods

Study population

The present study utilized data from the NHANES, a nationally representative survey conducted by the National Center for Health Statistics (NCHS) of the Centers for Disease Control and Prevention [14]. The NHANES employs a complex, multistage, probability sampling design to select participants representative of the noninstitutionalized civilian population of the United States. Data are collected through a combination of in-home interviews, standardized physical examinations,

and laboratory assessments performed in mobile examination centers. The NHANES received approval from the NCHS Research Ethics Review Board, and all participants provided written informed consent before participating in the survey.

A total of 70,190 participants from NHANES 2005–2018 were initially identified for this study. Individuals aged < 20 years (n = 30,441) were excluded, as the LS7, LE8, and LC9 metrics are specifically designed to assess CVH in adults [5, 6, 15]. Additional exclusions included pregnant participants (n = 708), individuals with baseline CVD (n = 4,441), and those with baseline cancer (n = 2,836). After these exclusions, 31,764 participants remained eligible for further analysis. Among these, 9,342 participants were excluded due to missing data on at least one component of the LC9 score, which requires data from eight or nine components to be computed. After this exclusion, 22,422 participants had complete LC9 data at baseline. Following additional exclusions due to ineligibility for mortality linkage due to insufficient identifying data or incomplete follow-up (n = 40), the final study population for survival analysis consisted of 22,382 participants (Additional file 1**:** Fig. S1).

Assessment of CVH metrics

The CVH metrics evaluated in this study included LS7, LE8, and LC9. These metrics, developed by the AHA, aim to provide a structured and comprehensive framework for assessing CVH through modifiable health behaviors and clinical factors [5, 6, 15]. LS7 is defined based on seven components: smoking status, BMI, physical activity, TC, blood pressure, FBG, and diet [5]. Each component was categorized into three levels—poor, intermediate, or ideal health—scored as 0, 1, or 2, respectively. The total LS7 score ranged from 0 to 14, with higher scores indicating better CVH. The detailed scoring criteria for each component are provided in Additional file 1**:** Table S1.

LE8, introduced in 2022 as an enhancement of LS7, incorporates an additional component, sleep health, and includes updated definitions for diet and smoking status to reflect advancements in CVH research [6]. The LE8 score was calculated on a continuous scale ranging from 0 to 100, with each component contributing equally. Scores for individual components were first standardized on a scale of 0 to 100 based on predefined thresholds, and the final LE8 score was derived as the mean of all component scores. The detailed scoring criteria for LE8 are provided in Additional file 1: Table S2.

LC9, an expanded version of LE8, integrates mental health as an additional component via the Patient Health Questionnaire-9 (PHQ-9), emphasizing the importance of psychological well-being in cardiovascular outcomes [15]. Like those of LE8, the LC9 scores were calculated on a continuous scale from 0 to 100. A valid LC9 score requires data for at least eight of the nine components, with the total score computed as the mean of available component scores. The detailed scoring criteria for LC9 are also provided in Additional file 1: Table S2.

Standardized protocols were used to assess each component of LS7, LE8, and LC9 during NHANES examinations. Smoking status, diet, physical activity, and mental health were assessed via validated self-report questionnaires, whereas BMI, blood pressure, TC, FBG, and sleep duration were measured objectively during mobile examination center visits. These metrics provide distinct yet overlapping insights into CVH, enabling a nuanced comparison of their ability to predict mortality outcomes in the general population.

Assessment of Mortality

The outcomes of this study included all-cause, CCD, and CVD mortality. Mortality data were obtained from the NHANES-linked National Death Index (NDI), which provides detailed information on mortality status and causes of death for NHANES participants. The follow-up period extended from the date of the NHANES examination until December 31, 2019. Cause-specific mortality was classified using the International Classification of Diseases, 10 th Revision (ICD-10) codes. Cardiovascular mortality was identified via the ICD-10 codes I00–I09, I11, I13, and I20–I51, whereas CCD mortality included these cardiovascular codes as well as cerebrovascular disease codes (I60–I69). The NHANES-linked NDI provides a validated and reliable source of mortality data.

Covariates

Demographic characteristics, socioeconomic factors, and behavioral variables were assessed via standardized NHANES questionnaires during in-home interviews. Demographic characteristics included age (continuous), sex (male or female), race/ethnicity (non-Hispanic White, non-Hispanic Black, or other race/ethnic groups), education level (below high school, high school graduate, and above high school), and marital status (married/living with a partner or single/divorced/widowed). The family poverty income ratio (PIR), an indicator of socioeconomic status, was calculated as the ratio of family income to the federal poverty level, adjusted for family size and inflation, and categorized into three groups: ≤ 1.0, 1.1–3.0, and > 3.0 [16, 17]. The behavioral covariates included drinking status, classified as nondrinker, low-to-moderate drinker (≤ 2 drinks/day for men and ≤ 1 drink/day for women), and heavy drinker (> 2 drinks/day for men and > 1 drink/day for women). All variables were assessed following NHANES standardized protocols

to ensure consistency and comparability across survey cycles.

Statistical analysis

To ensure the validity of our findings, appropriate sample weights, strata, and primary sampling units (PSUs) were incorporated into all analyses in accordance with NHANES analytic guidelines via the"survey"package in R to adjust for the NHANES survey design. Descriptive statistics were computed to summarize the baseline characteristics of the study population. Continuous variables are presented as the means and standard errors (SEs), whereas categorical variables are expressed as frequencies and percentages.

The distributions of LE8 and LC9 scores across different LS7 levels were visualized via box plots, and their correlations with LS7 were assessed via Pearson correlation analysis. Age- and sex-standardized mortality rates (per 1000 person-years) for all-cause, CCD, and CVD mortality were calculated by stratifying participants according to the number of CVH metrics. Mortality rates were directly standardized to the age and sex distributions of the entire cohort, and 95% confidence intervals (CIs) were computed for each group.

Cox proportional hazards regression models were employed to assess the associations between LS7, LE8, and LC9 scores and mortality outcomes, including all-cause and cause-specific mortality. The proportional hazards assumption was tested via Schoenfeld residuals, and if the assumption was violated, time-dependent covariates were included in the models. Multicollinearity among covariates was assessed via the variance inflation factor (VIF), with values below 10 indicating acceptable levels of multicollinearity. Fully adjusted models included potential confounders such as age, sex, race/ethnicity, education level, marital status, the family PIR, and drinking status. Hazard ratios (HRs) with 95% CIs were reported for each health score in relation to mortality outcomes.

To investigate the dose–response relationships between CVH metrics (LS7, LE8, and LC9) and mortality outcomes, restricted cubic spline (RCS) regression models were employed. Four knots were placed at the 5th, 35 th, 65 th, and 95 th percentiles of the respective health score distributions. Nonlinearity was assessed via likelihood ratio tests comparing the spline model to a linear model. Receiver operating characteristic (ROC) curves were constructed to assess the ability of the LS7, LE8, and LC9 scores to predict all-cause and cause-specific mortality at 3-year, 5-year, and 10-year follow-up intervals. The area under the curve (AUC) was calculated for each time point, and pairwise comparisons between the scores were performed via the DeLong test to compare AUCs across models.

Two sensitivity analyses were conducted to assess the robustness of the results. The first excluded participants who died within the first two years of follow-up to minimize bias from early mortality. The second analyzed mortality outcomes via all nine components of the LC9 (instead of at least eight, as in the primary analysis) to explore the impact of a more comprehensive CVH measure. Statistical analyses were performed via R version 4.3.2 (R Foundation for Statistical Computing). All the statistical tests were two-sided, with the significance level set at $p < 0.05$.

Results

Baseline Characteristics of the Participants

The baseline characteristics of the study population (n = 22,382) are summarized in Table 1. The mean age of the participants was 45.23 ± 0.23 years, and 51.53% were female. The racial/ethnic composition included 67.64% non-Hispanic White, 10.92% non-Hispanic Black, and 21.43% other racial/ethnic groups. The CVH scores resulted in a mean LS7 score of 8.47 ± 0.04, with 20.29% scoring ≤ 4 and 5.22% scoring ≥ 11. The mean LE8 score was 68.92 ± 0.25, and 24.12% of the participants scored below 50. For LC9, the mean score was 71.51 ± 0.23, with 5.91% scoring below 50.

Additional file 1: Fig. S2 demonstrates that the scores for LS7, LE8, and LC9 exhibit an approximately normal distribution. The distributions of LS7 components across poor, intermediate, and ideal categories, as well as the means (SEs) of the LE8 and LC9 components, are presented in Additional file 1: Table S3. Fig. 1 illustrates the distribution of LE8 and LC9 scores across different levels of LS7 scores. A strong positive correlation was observed between the LS7 and LE8 scores (Pearson $r = 0.91$, $P < 0.001$; Fig. 1A) as well as between the LS7 and LC9 scores (Pearson $r = 0.89$, $P < 0.001$; Fig. 1B).

Mortality rates by CVH scores

The Kaplan–Meier curves illustrate the cumulative incidence of all-cause, CCD, and CVD mortality across different levels of LS7 (Additional file 1: Fig. S3 A–C), LE8 (Additional file 1: Fig. S3D–F), and LC9 (Additional file 1: Fig. S3G–I) scores. Participants with higher CVH scores consistently presented lower cumulative mortality rates over a median follow-up period of 7.75 years (IQR: 4.42–11.08), with significant differences observed across score categories (all log-rank $P < 0.001$). Figure 2, with numeric estimates in Additional file 1: Table S4, shows age- and sex-standardized mortality rates for all-cause, CCD, and CVD mortality across different levels of LS7, LE8, and LC9. For LS7, mortality rates decreased consistently with

Table 1 Description of adult participants for demographic characteristics and components of the cardiovascular health score in NHANES 2005–2018 ($n = 22,382$)

Characteristics	Mean ± SE or n (%)
Age (years, mean ± SE)	45.23 ± 0.23
Sex (%)	
Female	11,570 (51.53%)
Male	10,812 (48.47%)
Race/ethnicity (%)	
Non-Hispanic White	9251 (67.64%)
Non-Hispanic Black	4830 (10.92%)
Other race	8301 (21.43%)
Education level (%)	
Below high school	4964 (14.09%)
High school	5134 (23.31%)
Above high school	12,284 (62.59%)
Marital status (%)	
Married/living with partner	13,592 (64.67%)
Single/divorced/widowed	8790 (35.33%)
Family PIR (%)	
≤ 1.0	4516 (13.35%)
1.1–3.0	9174 (34.96%)
> 3.0	8692 (51.70%)
HEI-2015 score (mean ± SE)	50.53 ± 0.20
Moderate-vigorous physical activity (min/week, mean ± SE)	736.91 ± 12.92
Smoking status (%)	
Never smoker	12,891 (57.38%)
Former smoker	4955 (23.17%)
Current smoker	4536 (19.45%)
Drinking status (%)	
Non-drinker	4832 (17.24%)
Low-to-moderate drinker	15,640 (72.76%)
Heavy drinker	1910 (10.00%)
Sleep times (h/day, mean ± SE)	6.87 ± 0.01
Body mass index (kg/m^2, mean ± SE)	29.02 ± 0.09
Total cholesterol (mg/dL, mean ± SE)	195.07 ± 0.48
HDL cholesterol (mg/dL, mean ± SE)	53.57 ± 0.19
HbA1c (%, mean ± SE)	5.56 ± 0.01
Systolic BP (mmHg, mean ± SE)	120.94 ± 0.22
Diastolic BP (mmHg, mean ± SE)	71.25 ± 0.20
Anti-hypertensive drugs (%)	
No	16,743 (78.23%)
Yes	5639 (21.77%)
Diabetes mellitus, n (%)	
No	18,893 (88.63%)
Yes	3489 (11.37%)
PHQ-9 score (mean ± SE)	2.87 ± 0.04
Life's Simple 7 score (%)	
≤ 4	3972 (20.29%)
5–6	6314 (30.74%)
7–8	6555 (28.26%)
9–10	4074 (15.50%)
≥ 11	1467 (5.22%)
LS7 (0–14) score (mean ± SE)	8.47 ± 0.04
Life's Essential 8 score (%)	
< 50.0	4613 (24.12%)
50.0–59.9	5411 (25.91%)
60.0–69.9	5686 (24.56%)
70.0–79.9	4015 (15.86%)
> 79.9	2657 (9.57%)
LE8 (0–100) score (mean ± SE)	68.92 ± 0.25
Life's Crucial 9 score (%)	
< 50.0	1648 (5.91%)
50.0–59.9	3330 (12.72%)
60.0–69.9	5686 (23.90%)
70.0–79.9	6236 (29.06%)
> 79.9	5482 (28.41%)
LC9 (0–100) score (mean ± SE)	71.51 ± 0.23

Abbreviations: *PIR* poverty-to-income ratio, *HEI* Healthy Eating Index, *HDL* high-density lipoprotein, *HbA1c* glycated hemoglobin, *BP* blood pressure, *PHQ* Patient Health Questionnaire, *LS7* Life's Simple 7, *LE8* Life's Essential 8 score, *LC9* Life's Crucial 9. Continuous variables are described as means ± SEs. Categorical variables are presented as numbers (percentages). Sampling weights were applied for calculation of demographic descriptive statistics; N reflect the study sample while percentages reflect the survey-weighted data

higher scores. The participants with LS7 scores ≤4 had the highest all-cause mortality rate of 16.57 (95% CI: 13.52–19.63) per 1000 person-years, which decreased to 4.06 (95% CI: 2.82–5.30) per 1000 person-years for scores ≥11. The CCD and CVD mortality rates followed a similar pattern, declining from 4.42 (95% CI: 3.09–5.76) and 3.92 (95% CI: 2.61–5.22) per 1000 person-years, respectively, in the lowest score group to 1.14 (95% CI: 0.37–1.90) and 1.12 (95% CI: 0.36–1.89) per 1000 person-years, respectively, in the highest score group. LE8 and LC9 showed similar inverse trends, with higher scores consistently associated with lower mortality rates for all outcomes.

Associations between CVH scores and mortality outcomes

Figure 3 shows the adjusted HRs and 95% CIs for the associations between LS7, LE8, and LC9 scores and mortality outcomes, including all-cause, CCD, and CVD mortality, based on the fully adjusted model. For LS7 (Fig. 3A, Additional file 1: Table S5), participants with scores ≥11 had significantly lower risks of all-cause mortality (HR = 0.35, 95% CI: 0.25–0.50), CCD mortality (HR = 0.34, 95% CI: 0.16–0.73), and CVD mortality (HR = 0.39, 95% CI: 0.18–0.85) than those with scores ≤4 (reference group). Each 1-point increase in the LS7 score was associated with a 12% reduction in all-cause

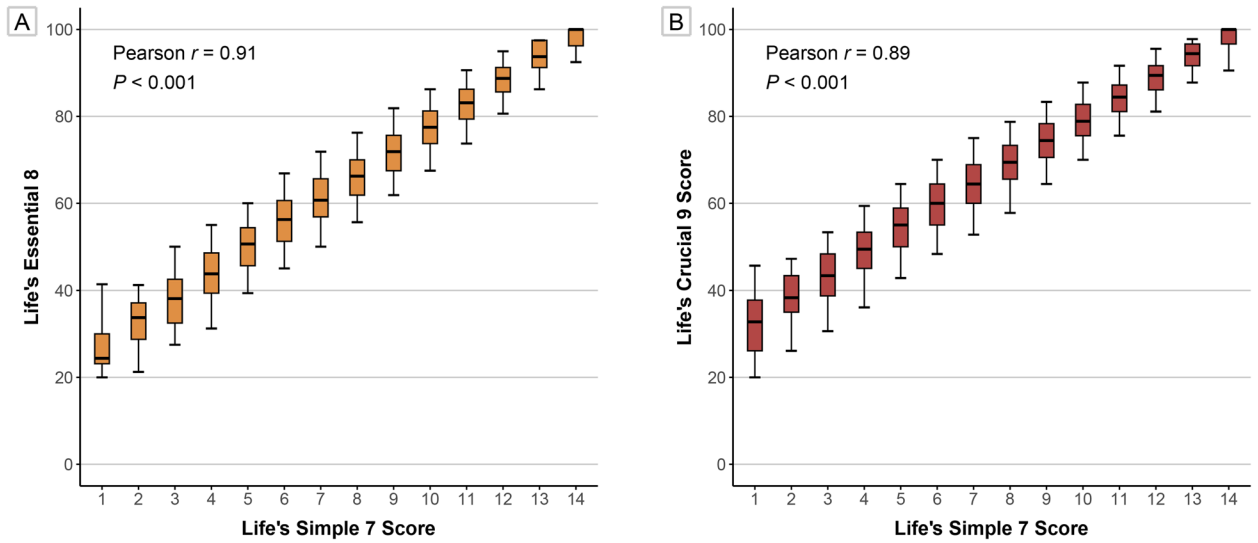

Fig. 1 Boxplots showing the distribution of LE8 and LC9 scores across LS7 score levels. Boxplots illustrate the distribution of Life's Essential 8 (LE8, panel A) and Life's Crucial 9 (LC9, panel B) scores across different levels of Life's Simple 7 (LS7). Pearson correlation coefficients indicate a strong positive relationship between LS7 and LE8 ($r = 0.91$, $P < 0.001$) and between LS7 and LC9 ($r = 0.89$, $P < 0.001$)

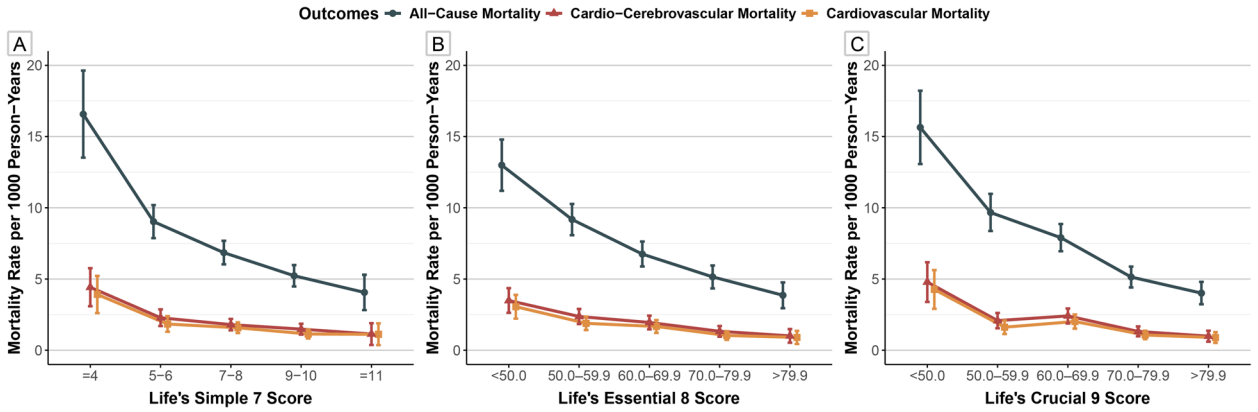

Fig. 2 Age- and sex-standardized mortality rates per 1000 person-years by cardiovascular health score levels. Standardized mortality rates for all-cause, cardio-cerebrovascular (CCD), and cardiovascular (CVD) mortality are presented across different levels of Life's Simple 7 (LS7, panel A), Life's Essential 8 (LE8, panel B), and Life's Crucial 9 (LC9, panel C). Rates were adjusted using the direct method of standardization, with the entire cohort's age and sex distribution as the reference. Error bars indicate 95% confidence intervals. Detailed numerical estimates are provided in Table S4

mortality risk (HR = 0.88, 95% CI: 0.85–0.91). RCS analysis confirmed a linear, negative association between LS7 scores and mortality outcomes (Additional file 1: Fig. S4 A–C).

For LE8 (Fig. 3B, Additional file 1: Table S6), participants scoring > 79.9 had significantly lower risks of all-cause mortality (HR = 0.38, 95% CI: 0.28–0.50), CCD mortality (HR = 0.32, 95% CI: 0.17–0.60), and CVD mortality (HR = 0.34, 95% CI: 0.18–0.65) than those scoring < 50. Each 10-point increase in the LE8 score was associated with a 21% reduction in all-cause mortality risk (HR = 0.79, 95% CI: 0.75–0.83). RCS analysis revealed a linear, negative association across all mortality outcomes (Additional file 1: Fig. S4D–F).

For LC9 (Fig. 3C, Additional file 1: Table S7), participants with scores > 79.9 had significantly lower risks of all-cause mortality (HR = 0.32, 95% CI: 0.24–0.42), CCD mortality (HR = 0.24, 95% CI: 0.14–0.42), and CVD mortality (HR = 0.25, 95% CI: 0.14–0.44) than those with scores < 50. Each 10-point increase in the LC9 score was associated with a 24% reduction in all-cause mortality risk (HR = 0.76, 95% CI: 0.72–0.81). RCS analysis

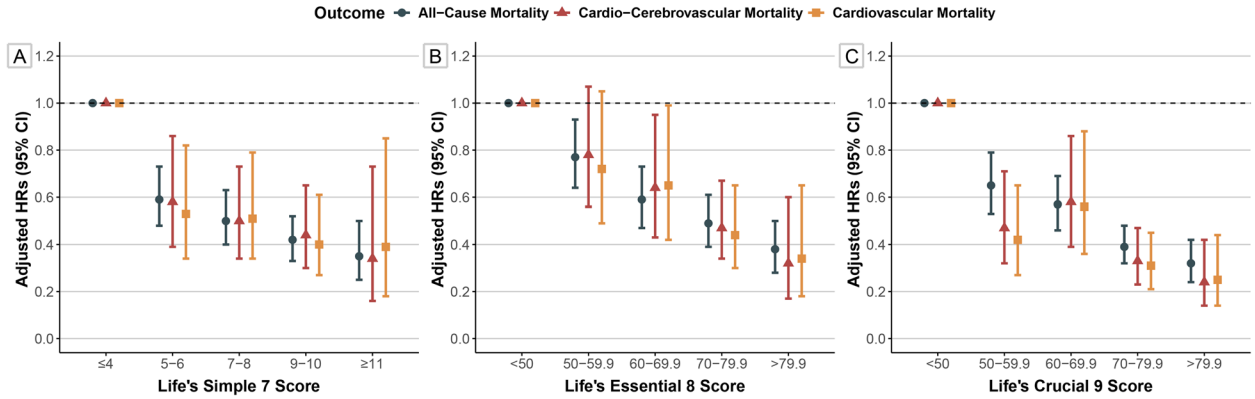

Fig. 3 Cox regression analysis of adjusted hazard ratios (HRs) and 95% confidence intervals (CIs) for mortality outcomes by cardiovascular health scores. Hazard ratios for all-cause, cardio-cerebrovascular (CCD), and cardiovascular (CVD) mortality are presented across different levels of Life's Simple 7 (LS7, panel A), Life's Essential 8 (LE8, panel B), and Life's Crucial 9 (LC9, panel C). Hazard ratios were adjusted for age (continuous), sex (male or female), race/ethnicity (non-Hispanic White, non-Hispanic Black or other race), education level (below high school, high school, or above high school), marital status (married/living with partner, or single/divorced/widowed), family PIR (≤ 1.0, 1.1–3.0, or > 3.0), and drinking status (never drinker, former drinker, or current drinker). Detailed numerical estimates for LS7, LE8, and LC9 are provided in Table S5, Table S6, and Table S7, respectively

confirmed a linear, negative association for all outcomes (Additional file 1: Fig. S4G–I).

Predictive accuracy of CVH scores

Figure 4 displays the ROC curves for LS7, LE8, and LC9 in predicting all-cause, CCD, and CVD mortality at the 3-, 5-, and 10-year follow-ups. For all-cause mortality, LS7 demonstrated comparable predictive accuracy to LE8 and LC9. At 3 years (Fig. 4A), the AUC for LS7 was 0.679 (0.651–0.706), which was slightly greater than those for LE8 (0.670 [0.642–0.697]) and LC9 (0.674 [0.646–0.701]). At 5 years (Fig. 4B), LS7 maintained an AUC of 0.683 (0.663–0.704), similar to those of LE8 (0.668 [0.648–0.689]) and LC9 (0.669 [0.649–0.690]). By 10 years (Fig. 4C), LS7 had an AUC of 0.668 (0.652–0.685), whereas LE8 (0.643 [0.626–0.660]) and LC9 (0.642 [0.625–0.659]) had slightly lower values. Pairwise comparisons revealed statistically significant differences in the AUC between LS7 and LE8 or LC9 at the 5-year and 10-year time points (all $P < 0.05$). However, the AUC values for LS7, LE8, and LC9 were nearly identical overall. For CCD mortality (Fig. 4D–F) and CVD mortality (Fig. 4G–I), the predictive performance was similar across the three metrics, with small differences observed in the AUC values.

Additionally, Additional file 1: Fig. S5 shows the incremental value of LS7, LE8, and LC9 in enhancing the performance of the fully adjusted baseline model (including age, sex, race/ethnicity, education level, marital status, family PIR, and drinking status) for all-cause, CCD, and CVD mortality. The addition of LS7 (AUC = 0.840 [0.824–0.856], $P < 0.001$), LE8 (AUC = 0.839 [0.823–0.855], $P < 0.001$), and LC9 (AUC = 0.841 [0.825–0.857], $P < 0.001$) to the baseline model (AUC = 0.834 [0.818–0.850], $P < 0.001$) significantly improved all-cause mortality predictions at 5 years; however, the actual gains in predictive performance were marginal.

Sensitivity analyses

Sensitivity analyses confirmed the robustness of the associations between CVH scores and mortality outcomes. After excluding participants who died within two years of follow-up, higher scores for LS7, LE8, and LC9 remained significantly associated with reduced risks of all-cause, CCD, and CVD mortality (Additional file 1: Table S8). Similarly, restricting the analysis to participants with complete data for all nine LC9 components at baseline (instead of at least 8, as in the primary analysis) yielded consistent results, with significant dose–response relationships observed across all scores (all P for trend < 0.001, Additional file 1: Table S9).

Discussion

This study evaluated the predictive performance of the LS7, LE8, and LC9 metrics for all-cause, CCD, and CVD mortality among 22,382 participants from NHANES 2005–2018. We found that higher scores on all three metrics were significantly associated with lower mortality risk. Although LE8 and LC9 incorporate additional components and more refined scoring criteria, LS7, with its simpler structure and fewer components, demonstrated comparable predictive performance. These results indicate that while LS7 remains an effective tool for mortality prediction, the increased complexity of LE8 and LC9

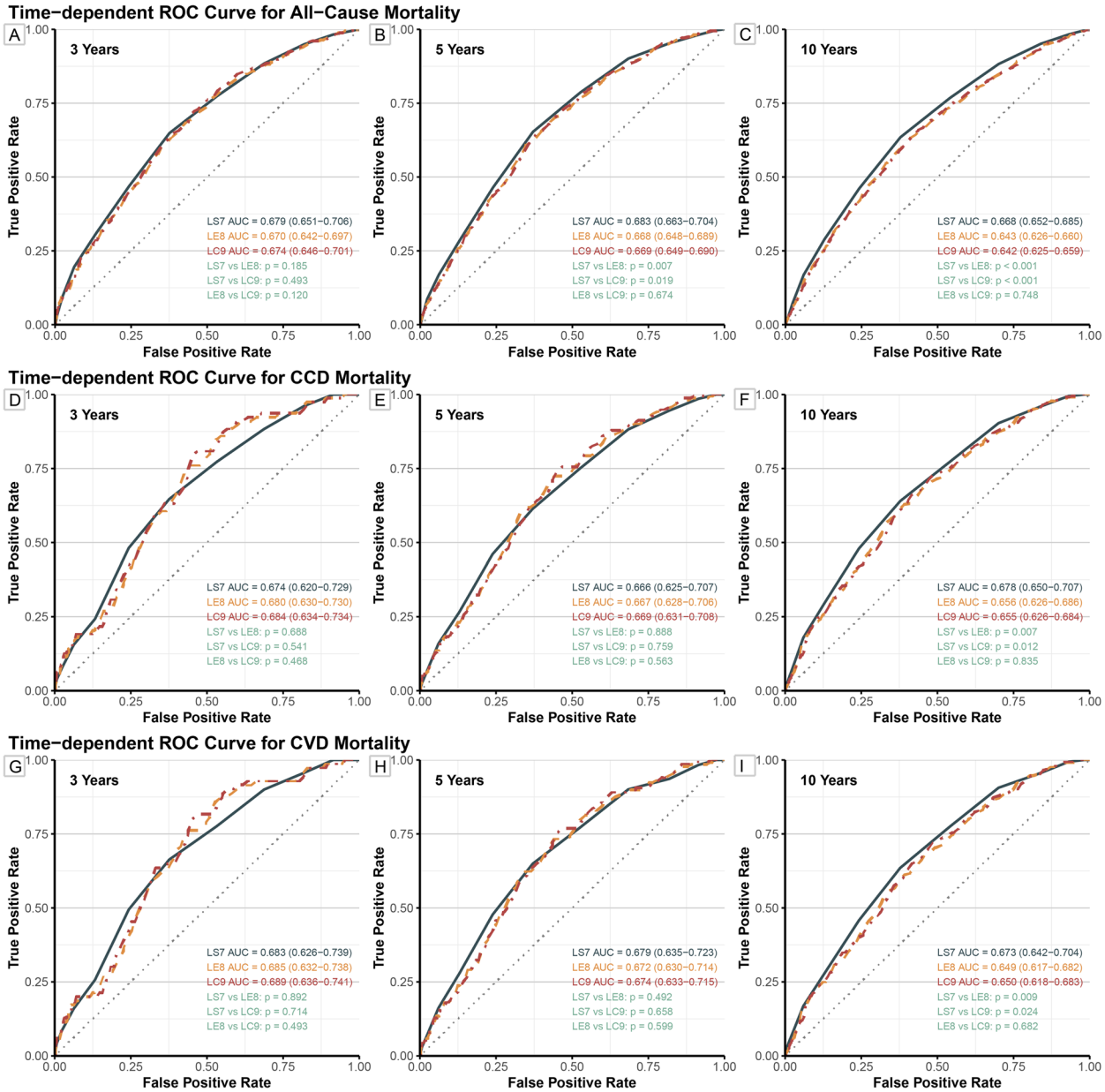

Fig. 4 Receiver operating characteristic (ROC) curves for the predictive performance of cardiovascular health scores. ROC curves for predicting all-cause mortality (panels A–C), cardio-cerebrovascular (CCD) mortality (panels D–F), and cardiovascular (CVD) mortality (panels G–I) are presented for Life's Simple 7 (LS7), Life's Essential 8 (LE8), and Life's Crucial 9 (LC9) at 3-, 5-, and 10-year follow-ups

does not lead to significant improvements in predictive accuracy. Owing to its simplicity, LS7 may offer practical advantages for clinical application.

The transition from LS7 to LE8 and LC9 introduced several updates, including replacing FBG with either FBG or HbA1c, reflecting current clinical practices [5, 6, 15]. While HbA1c provides a better indication of long-term glycemic control, it introduces variability by measuring different aspects of glycemia. Additionally, smoking metrics were expanded to include inhaled noncigarette products and secondhand smoke, while TC was replaced with non-high-density lipoprotein cholesterol for a more comprehensive lipid profile [6]. LE8 and LC9 introduced more detailed scoring criteria not only by incorporating sleep health and depression but also by refining the classifications for BMI, physical activity, blood pressure, and diet [6, 15]. While these changes enhance the comprehensiveness of LE8 and LC9, they increase complexity,

which may limit direct comparisons with the simpler LS7. This added complexity, along with updated scoring thresholds and metrics, may alter overall scores and affect risk stratification. Our study addresses this issue by directly comparing the predictive accuracy and risk stratification capabilities of LS7, LE8, and LC9, providing insights into whether the increased complexity of LE8 and LC9 truly improves predictive accuracy or if LS7's simpler approach remains sufficient.

Higher CVH scores have consistently been associated with lower mortality risks across diverse populations. Zhou et al. reported that higher LS7 scores corresponded to a 54% reduction in all-cause mortality over more than two decades of follow-up in a Chinese cohort [18]. These findings align with other research showing that each additional point on the LS7 scale results in a 20–31% decrease in the risk of CVD and mortality [19], emphasizing the critical role of the LS7 as a straightforward yet effective indicator of CVH. Importantly, even individuals with high genetic susceptibility to CVD benefit from achieving ideal LS7 levels, underscoring the enduring value of lifestyle modification in mitigating mortality risk [20].

In our study, LS7 was similarly strongly associated with all-cause and cardiovascular mortality. However, unlike previous findings, we observed that the inclusion of additional components in LE8 and LC9—designed to capture broader dimensions of CVH—did not yield meaningful improvements in predictive accuracy. While studies such as those by Huang et al. reported that lower all-cause mortality was associated with higher LE8 scores in CVD patients, our data suggest that these expanded metrics provide limited additional predictive value over LS7 [21]. Moreover, while the curvilinear dose–response relationship of LE8 [22] and small reductions in adverse outcomes per point increase [10] have been noted in prior analyses, these findings did not translate into superior performance compared with that of LS7 in our broader, more diverse cohort.

Recent studies have compared the predictive performance of LS7, LE8, and LC9, offering valuable insights into their relative effectiveness. LS7, a well-established and straightforward CVH metric, has long been regarded as a reliable predictor of cardiovascular outcomes. The subsequent introduction of LE8 incorporated additional sleep health information while also refining the scoring criteria to provide a more comprehensive assessment. However, these enhancements have not consistently translated into significant improvements in predictive accuracy. Howard et al. analyzed data from the REGARDS study, which included 11,609 Black and White community-dwelling adults aged 45 years or older, and reported that LS7 and LE8 had nearly identical C-statistics for predicting 10-year incident CVD risk (0.691 vs. 0.695, $P = 0.12$) [23]. Similarly, Naman et al. reported no significant difference between LE8 and LS7 in predicting all-cause or cardiovascular mortality among adults aged 40–79 years [24]. In contrast, our study was based on a larger, more inclusive adult population and simultaneously evaluated LS7, LE8, and LC9. This direct comparison offers clinical value by evaluating the relative predictive performance of these metrics, an aspect not previously explored; it helps determine whether the added complexity CVH metrics improve risk prediction over the simpler LS7, aiding clinicians in selecting the most effective tool for CVH assessment.

Furthermore, the inclusion of mental health metrics in LC9 has shown only marginal benefits. Ge et al. [7] reported that adding a depression score to LE8 did not significantly improve its ability to predict mortality outcomes, whereas Dinh et al. reported minimal differences in C statistics between LE8 and more complex CVH constructs that incorporated mental health factors (0.843 vs. 0.842, $P < 0.001$) [25]. These findings indicate that although the inclusion of psychological metrics may align with a broader view of CVH, their practical value in enhancing mortality prediction is limited. In line with these previous studies, our results show that while LE8 and LC9 introduce meaningful conceptual refinements, LS7 remains a robust, accessible, and equally effective tool; this highlights the importance of balancing simplicity with comprehensiveness in the development and application of CVH metrics.

LS7, LE8, and LC9 are highly correlated due to their shared components and similar scoring frameworks. Traditional risk factors, such as hypertension, diabetes, and obesity, may act as intermediaries in the link between poor sleep and mortality risk [26]. Sleep disturbances are increasingly recognized as critical factors influencing CVH [27]. Reduced sleep has been shown to affect the levels of key hormones involved in regulating appetite, specifically ghrelin and leptin, leading to an increased risk of weight gain and obesity associated with chronic sleep deprivation [28]. Furthermore, sleep problems consistently increase the likelihood of hypertension, diabetes, and obesity [29, 30]. Therefore, the mortality risk attributed to poor sleep quality or insufficient sleep may be indirectly captured through the traditional risk factors included in LS7, which could explain why the addition of sleep as a metric in LE8 does not significantly increase predictive accuracy.

Similarly, depression is both a cause and a consequence of cardiovascular risk factors such as high blood pressure and obesity [31]. Positive psychological health plays a critical role in maintaining and improving health behaviors, particularly in managing chronic diseases [31].

Depression can significantly impact lifestyle behaviors, increasing the risk of CVD and other chronic conditions [32]. Meta-analyses involving 198,589 individuals aged 60 years or older revealed that older adults with depression were more likely to have a high risk of all-cause and CVD mortality [33]. Both the LS7 and LE8 scores were found to have a tangible and significant impact on depression, with LE8 exhibiting a stronger association [34]. Since the relationship between depression and cardiovascular outcomes is partially mediated by traditional risk factors, the unique contribution of depression may be diluted or redundant when combined with the LE8 score.

Additionally, both sleep and mental health are complex and multidimensional. Our study relied on self-reported measures of sleep duration and depression, which may not fully capture the quality or severity of these factors[35, 36]. As such, the assessment may have been insufficiently detailed to detect a significant additional effect on mortality prediction compared with the traditional cardiovascular risk factors already included in the models. The effects of sleep and mental health on mortality may vary across different subpopulations [37]. In our broad population sample, these factors may not have had as strong an impact as they would in more vulnerable groups, such as older adults or individuals with preexisting conditions. While these variables are important, their influence may not have been fully captured within the context of our study's design. Finally, while we used robust statistical models, other unmeasured factors, such as medication use or health care access, may have further influenced the relationship between these psychosocial factors and mortality. Thus, while the inclusion of sleep and mental health in LE8 offers a more comprehensive assessment of CVH, their contribution to mortality prediction may not be as pronounced in this population, and their effect could be largely mediated by other traditional risk factors.

In comparing LS7, LE8, and LC9, our study highlights the strengths and weaknesses of each tool in terms of ease of use, cost, and patient acceptance. LS7 is simple to administer, relies on readily available clinical data, and is cost effective, making it an ideal choice for both clinical settings and large-scale population screenings [23]. Despite its simplicity, LS7 demonstrated comparable predictive performance to LE8 and LC9 in our study, making it a reliable tool for assessing CVH. LE8 introduces additional complexity by incorporating sleep health and refining scoring criteria, but this comes at the cost of requiring more data and potentially increasing time and resource demands. LC9 adds mental health metrics, but the subjective nature of these assessments introduces variability and additional complexity, limiting its feasibility in routine practice. Given that LS7 offers comparable predictive accuracy with lower cost and greater simplicity, we recommend its continued use in clinical and public health applications.

Our study is the first to compare the mortality risk prediction value of all three CVH scores, LS7, LE8, and LC9. By evaluating LS7, LE8, and LC9 simultaneously and multiple endpoints, this study analyzed the performance of these CVH tools in predicting mortality outcomes among 22,382 participants from the NHANES and provided a thorough assessment of their relative strengths and weaknesses. The AHA designed these tools to encourage widespread adoption of healthy behaviors, aiming to reduce the prevalence of CVD risk factors and lower rates of CVD-related morbidity and mortality. By targeting these traditional risk factors, all scores demonstrated strong associations with CCD and all-cause mortality. While the associations of CVH scores with mortality are promising and align with established knowledge about CVH, careful interpretation should be considered. Future research is needed to strengthen causal inferences, particularly through longitudinal and interventional studies. These studies could provide deeper insights into how long-term changes in CVH scores influence mortality and morbidity risks associated with cardiovascular and other chronic diseases.

Several limitations should be considered in this study. First, some sociodemographic and socioeconomic variables, such as physical activity, diet, and mental health, are based on self-reported data, which are susceptible to recall bias and inaccuracies, potentially affecting the precision of the scores. Second, although the median follow-up period was substantial, it may not fully capture long-term mortality trends. Third, all three CVH scores were measured only at baseline, and changes in CVH scores over time were not assessed. While some studies suggest that CVH scores may remain relatively stable or decline over time in the general population, further research is needed to investigate the impact of these changes on mortality outcomes. Fourth, despite accounting for several potential confounders, unmeasured variables such as other chronic comorbidities could still influence the outcomes. Additionally, the severity of depression in our study population may have been mild, leading to a smaller, less detectable effect on mortality outcomes. Future studies with larger sample sizes, longer follow-up periods, and stratified analyses based on depression severity would provide valuable insights.

Conclusions

This study demonstrated that LS7, LE8, and LC9 effectively predict all-cause, CCD, and CVD mortality in a nationally representative population. While LE8 and

LC9 incorporate additional components such as sleep and mental health and detailed scoring criteria, these enhancements did not significantly improve predictive accuracy. LS7 demonstrated comparable performance in predicting mortality, and with its simpler structure and scoring, it remains a practical and reliable tool for improving CVH and reducing mortality in both clinical and public health efforts.

Abbreviations

AHA	American Heart Association
AUC	Area Under the Curve
BMI	Body Mass Index
CCD	Cardio-Cerebrovascular Disease
CIs	Confidence Intervals
CVD	Cardiovascular Disease
FBG	Fasting Blood Glucose
HRs	Hazard Ratios
ICD-10	International Classification of Diseases, 10th Revision
LC9	Life's Crucial 9
LE8	Life's Essential 8
LS7	Life's Simple 7
NCHS	National Center for Health Statistics
NDI	National Death Index
NHANES	National Health and Nutrition Examination Survey
PHQ-9	Patient Health Questionnaire-9
RCS	Restricted Cubic Spline
ROC	Receiver Operating Characteristic
SEs	Standard Errors
TC	Total Cholesterol
VIF	Variance Inflation Factor
WTMEC2YR	Weighting Variable for 2-Year Cycle of NHANES

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12916-025-04116-9.

Additional file 1: Fig. S1 Flowchart of the study. Fig. S2 Distribution of cardiovascular health scores among adults in NHANES 2005–2018. Fig. S3 Kaplan-Meier curves for cumulative incidence of mortality by cardiovascular health scores levels. Fig. S4 Restricted cubic spline analyses of cardiovascular health scores and mortality outcomes. Fig. S5 Incremental predictive value of cardiovascular health scores for mortality outcomes. Table S1 Definition and scoring approach for the American Heart Association's Life's Simple 7 score. Table S2 Definition and scoring approach for the American Heart Association's Life's Essential 8 score or Life's Crucial 9 score. Table S3 Distribution of LS7 components across poor, intermediate, and ideal categories, and mean (standard error) of LE8 and LC9 components in NHANES 2013–2014. Table S4 Age- and sex-standardized mortality rates per 1000 person-years of all-cause and cause specific mortality by cardiovascular health score. Table S5 Associations of the Life's Simple 7 score with all-cause and cause specific mortality among adults in NHANES 2005–2018. Table S6 Associations of the Life's Essential 8 score with all-cause and cause specific mortality among adults in NHANES 2005–2018. Table S7 Associations of the Life's Crucial 9 score with all-cause and cause specific mortality among adults in NHANES 2005–2018. Table S8 Associations of the cardiovascular health score with all-cause and cause specific mortality among adults after excluding participants who died within one years of follow-up in NHANES 2005–2018. Table S9 Associations of the cardiovascular health score with all-cause and cause specific mortality among participants with data on all 8 components of the LE8 at baseline (instead of at least 7, as in the primary analysis) in NHANES 2005–2018.

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Authors' contributions
The authors' responsibilities were as follows—LZ, HZ and XL: designed the research, and had primary responsibility for the final content; XZ: conducted analyses and wrote the first draft of the paper; IC, YF, SC, GL, and HY: revised the manuscript; and all authors: read and approved the final manuscript and approved the final submitted version.

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Data availability
NHANES data described in this manuscript are available at https://wwwn.cdc.gov/nchs/nhanes/.

Declarations

Ethics approval and consent to participate
All participants provided written informed consent, and the study procedures were approved by the National Center for Health Statistics Research Ethics Review Board (Protocol Number: Protocol #2005–06 and Protocol #2011–17).

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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