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Original Article

Development of a cardiovascular health score for diabetics based on the weighting of the contribution of diabetes-related mortality

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Abstract: Background: Diabetes-related mortalities encompass multiple causes, including cardiovascular disease, infections, and diabetic nephropathy, with cardiovascular death being the leading cause among them. This study aimed to develop a cardiovascular health score specifically suited for diabetic patients based on the Life's Essential 8 scoring system. Methods: The study included 23,310 adults from the National Health and Nutrition Examination Survey (NHANES) and determined their mortality cause by linking the data to the National Death Index. The primary outcomes encompassed diabetes-related mortality, cardiovascular mortality, and all-cause mortality. Assessment of mortality risk by Cardiovascular Health (CVH) using cox proportional risk modeling. Weighted quantile sum regression models were utilized to evaluate the contributions of eight CVH factors within their combined effects. Based on the results, the contributions of each factor were adjusted to create a new CVH score. The X-tile figure was used to select the optimal threshold value for reclassifying CVH levels in diabetic patients. The C-index and Decision Curve Analysis were applied to compare the predictive performance of the new CVH level with the original CVH level. Results: Among the 23,310 adults who participated in the study, 15,217 were normoglycemic, 5,923 were prediabetic, and 2,170 were diabetic. Among the three glycemic states, diabetics exhibited the highest diabetes-related mortality rate (4.52%), and also had the highest cardiovascular mortality rate (3.09%). For all subjects, the risk of diabetes-related mortality decreased by 51.13% for every 10-point increase in the total CVH score, the most important CVH component was blood glucose (contribution of 64.6%). For diabetics, the most important CVH component was blood pressure (contribution of 35.7%), followed by tobacco/nicotine exposure and diet quality (contribution of 18.7% and 18.5%). Notably, the newly adjusted CVH score, unlike the original one, was significantly associated with cardiovascular death (HR = 0.9720, 95% CI: 0.9573 to 0.9869). We chose 30 and 60 as cutoff values for reclassifying CVH levels in diabetic patients. The DCA results indicated that the reclassified CVH levels were superior predictors of diabetes-related deaths, cardiovascular deaths, and all-cause mortality in diabetic patients compared to the original CVH levels. Conclusion: The weight-adjusted CVH score effectively predicted the risk of cardiovascular mortality in diabetics. The predictive performance of the reclassified CVH levels exhibited significant improvement over the original CVH levels. Additionally, when managing health, greater emphasis should be placed on encouraging diabetic patients to monitor their blood pressure, quit smoking, and maintain a healthy diet.

Keywords: Cardiovascular health, diabetic, component contributions, diabetes-related mortality

Introduction

The U.S. Centers for Disease Control and Prevention's 2020 National Diabetes Statistics Report estimates that 34.5% of American adults (18 years and older) meet the pre-diabetes criteria, and 13% have diabetes [1]. Hyperglycemia not only directly damages vascular endothelial cells [2-4] and accelerates the development of atherosclerosis [5]. Hyperglycemia also indirectly increases the risk of cardiovascular disease by affecting blood lipid levels, increasing inflammation and thrombosis [6-8]. Diabetes and cardiovascular disease have many similar risk factors in the occurrence and progression of the disease [9]. Concurrently, cardiovascular disease remains the primary cause of mortality among diabetic patients [10, 11]. The development of a cardiovascular health index tailored for diabetics is thus crucial

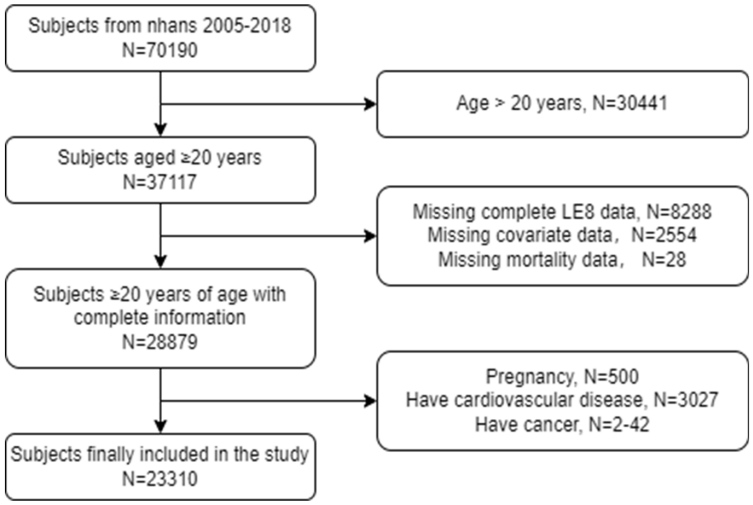

Figure 1. Flowchart for study sample selection based on inclusion and exclusion criteria.

for helping manage their health and reduce excessive mortality risks.

The American Heart Association (AHA) first proposed the concept of Ideal Cardiovascular Health (ICVH) in 2010, which was initially defined using the Life's Simple 7 (LS7) scoring system [12, 13]. After decades of decline in cardiovascular disease (CVD) mortality, the AHA updated the definition of Cardiovascular Health (CVH) in 2022. Based on the original seven indicators, the indicator of 'sleep health' was added to constitute Life's Essential 8 (LE8), which was used as a new scoring standard [14]. According to the criteria proposed by the AHA, individuals can be classified into three categories: low-level cardiovascular health, medium-level cardiovascular health, or high-level cardiovascular health. This classification system helps both the public and medical service providers to more easily identify high-risk groups for cardiovascular disease, enabling them to take appropriate intervention measures aimed at reducing the overall risk of cardiovascular disease in the population. The specific differences between the LS7 scoring system and the LE8 scoring system are listed in Table S1. Since the update of the scoring criteria in 2022, studies have shown that people with lower LE8 scores are more likely to have adverse cardiovascular events [15], and maintaining a higher LE8 score can reduce the risk of cardiovascular disease occurrence and mortality [16-18]. However, to the best of our knowledge, there is no study to evaluate the relationship between CVH defined by LE8 and diabetes-related mortality.

The purpose of this study is to explore the association between CVH, as defined by LE8, and diabetes-related mortality. By analyzing the contribution of the eight factors that comprise CVH to diabetes-related mortality, we aim to identify the more crucial health factors for diabetic patients. Subsequently, we will adjust the scoring criteria based on the contribution of each factor, in order to develop a scoring system that is more tailored to helping diabetic patients manage their cardiovascular health.

Methods

Study design and population

The baseline data of the National Health and Nutrition Survey (NHANES) database from 2005 to 2018 were accurately matched with the mortality records of NDI through the unique identification sequence number (SEQN) of the study subjects. A total of 23,310 American adults were included in the analysis after excluding subjects under 20 years of age, missing data, pregnancy, cardiovascular disease, or cancer (**Figure 1**). NHANES was approved by the Research Ethics Review Board of the National Centers for Health Statistics. All participants provided informed consent, and detailed information was provided by the U.S. Centers for Disease Control and Prevention (https://www.cdc.gov/nchs/nhanes/index.htm). Data used in this study were de-identified and publicly available.

Assessments of CVH

Cardiovascular health was assessed using the Life's Essential8 (LE8) scoring system proposed by the AHA [14]. The definitive scoring criteria pertaining to the LE8 system are exhaustively enumerated and elucidated in Table S2. Healthy Eating Index-2015 (HEI-2015) was calculated by using the average value of each

dietary component collected in two discontinuous 24-hour dietary recalls at baseline to assess dietary quality. Information on physical activity (self-reported weekly minutes of moderate or vigorous physical activity), tobacco/nicotine exposure (flammable tobacco use and secondhand smoke exposure), sleep health (sleep duration), and drug use was collected through standardized questionnaires. Weight, standing height, and blood pressure were collected at a mobile examination center (MEC). BMI is calculated by dividing body weight (kg) by the square of standing height (m). The mean of all available blood pressure measurements at baseline was used to estimate systolic and diastolic blood pressure. Serum cholesterol was determined by the enzymatic method. The calculation method of non-high-density lipoprotein cholesterol is total cholesterol minus high-density lipoprotein cholesterol. Glycosylated hemoglobin (HbA1c) was determined by high-performance liquid chromatography. According to the guidelines of the AHA, the total CVH score was obtained by summing and averaging the scores of individual LE8 components, and this score was subsequently categorized into three CVH levels: high (CVH total score ≥ 80), medium (50 ≤ CVH total score < 80), and low (CVH total score < 50) [14].

Assessments of covariates

We obtained information on age, gender, race, education, family income, and marriage through self-report questionnaires, and divided races into non-Hispanic whites, non-Hispanic blacks, Hispanics, and others (including Asian or multiracial) through standardized questionnaires; the marital status was divided into divorce/separation/widowhood, unmarried, married/cohabitation. The education level was divided into less than high school education, high school education, junior college education, and university education and above. The ratio of household income to poverty (PIR) is the ratio of the value of household income to the official poverty line, and the subjects were divided into three income levels: low (PIR < 1.3), medium (1.3 ≤ PIR < 3.5) and high (PIR ≥ 3.5).

Assessments of death

According to the 10th edition of the International Classification of Diseases (ICD-10), deaths caused by diabetes can only be coded in multiple cause-of-death codes. Therefore, as long as the ICD-10 code is found to be E10-E14 in the multiple causes of death codes of the participants, it is defined as diabetes-related mortality. Cardiovascular death was defined as ICD-10 coded as I00-I09, I11, I13, I20-I51.

Statistical analysis

Starting from the baseline questionnaire survey in the NHANS and ending at the earliest event of the death outcome or the end of follow-up, the time interval was calculated as the survival time. We divided the population into three subgroups according to blood glucose status: normal blood glucose (no history of diabetes, and HbA1c < 5.7%), pre-diabetes (no history of diabetes, and HbA1c 5.7-7.0%) and diabetes (diabetes diagnosed or HbA1c > 7.0%).

Primarily, the Schoenfeld Residuals Method serves to validate whether the model adheres to the proportional hazards assumption. COX proportional regression risk model was used to evaluate the relationship between CVH and diabetes-related mortality. The Kaplan-Meier (K-M) method was used to estimate the diabetes-related mortality of American adults with different CVH levels, and the log-rank test was used to compare the difference in survival probability. Regression analysis was performed using the R package 'survival', and the KM curve was drawn using the R package 'survminer'. In addition, we looked at regression results after adjusting for demographic variables to control for the effects of confounders.

The Pearson correlation coefficient was calculated to evaluate whether there was a significant correlation between CVH components. Subsequently, the score of a single LE8 component was regarded as a continuous variable, and The Weighted Quantile Sum (WQS) regression model was used to evaluate the mixed effect of CVH and diabetes-related mortality. The corresponding weight of each component of CVH showed its contribution to the overall effect. Sensitivity analysis of the WQS results was conducted by adjusting for variables including gender, age, race, marital status, education level, and family income. Based on HbA1c values and diabetes history, the total population was divided into normal blood glucose, pre-diabetes, and diabetes groups for subgroup analysis. WQS model analysis was performed using

Table 1. Baseline characteristics of American adult participants with different glycemic states

	Normal (N = 15217)	Prediabetes (N = 5923)	Diabetes (N = 2170)
Sex, n (%)			
Female	7804 (51.28)	3027 (51.11%)	1053 (48.53%)
Male	7413 (48.72%)	2896 (48.89%)	1117 (51.47%)
Age, n (%)			
60 years and over	2349 (15.44%)	2410 (40.69%)	1020 (47.00%)
40-59 years	5055 (33.22%)	2387 (40.30%)	940 (43.32%)
20-39 years	7813 (51.34%)	1126 (19.01%)	210 (9.68%)
Race and ethnicity, n (%)			
Non-Hispanic whites	7126 (46.83%)	1975 (33.34%)	589 (27.14%)
Non-Hispanic blacks	2578 (16.94%)	1659 (28.01%)	607 (27.97%)
Hispanic	3793 (24.93%)	1603 (27.06%)	729 (33.59%)
Others	1720 (11.30%)	686 (11.58%)	245 (11.29%)
Education levels, n (%)			
University education and above	4159 (27.33%)	1182 (19.96%)	358 (16.50%)
Junior college	4802 (31.56%)	1678 (28.33%)	622 (28.67%)
High school	3381 (22.22%)	1460 (24.65%)	476 (21.94%)
Less than high school	2875 (18.89%)	1603 (27.06%)	714 (32.91%)
Family income, n (%)			
Low	4517 (29.68%)	1843 (31.11%)	741 (34.15%)
Intermediate	5504 (36.17%)	2321 (39.19%)	886 (40.83%)
High	5196 (34.15%)	1759 (29.70%)	543 (25.02%)
Marriage, n (%)			
Divorced/Separated/Widowed	2428 (15.96%)	1498 (25.29%)	577 (26.59%)
Unmarried	3653 (24.01%)	781 (13.19%)	242 (11.15%)
Married/Cohabiting	9136 (60.04%)	3644 (61.52%)	1351 (62.26%)
CVH score, mean (SD)	71.57 (13.16)	60.88 (12.59)	53.69 (12.83)
CVH level, n (%)			
Low	894 (5.88%)	1202 (20.29%)	848 (39.08%)
Moderate	9757 (64.12%)	4316 (72.87%)	1286 (59.26%)
High	4566 (30.01%)	405 (6.84%)	36 (1.66%)
Diabetes-releated mortality, n (%)			
Alive	15204 (99.91%)	5888 (99.41%)	2072 (95.48%)
Dead	13 (0.09%)	35 (0.59%)	98 (4.52%)
Cardiovascular death, n (%)			
Alive	15204 (99.91%)	5888 (99.41%)	2072 (95.48%)
Dead	13 (0.09%)	35 (0.59%)	98 (4.52%)
All-cause mortality, n (%)			
Alive	15204 (99.91%)	5888 (99.41%)	2072 (95.48%)
Dead	13 (0.09%)	35 (0.59%)	98 (4.52%)

the R package 'gWQS', and correlation analysis was performed using SAS (version 9.4).

We meticulously selected the optimal cut-off points for the new CVH scores utilizing an X-tile plot approach. This methodology ensures a precise delineation of CVH levels, tailored specifically for this patient population. X-tile creates distinct training and validation cohorts by segregating observations into "censored" and "uncensored" lists, ordered by follow-up duration. It alternately assigns patients to these sets, effectively balancing the base survival curves. This standardization ensures consis-

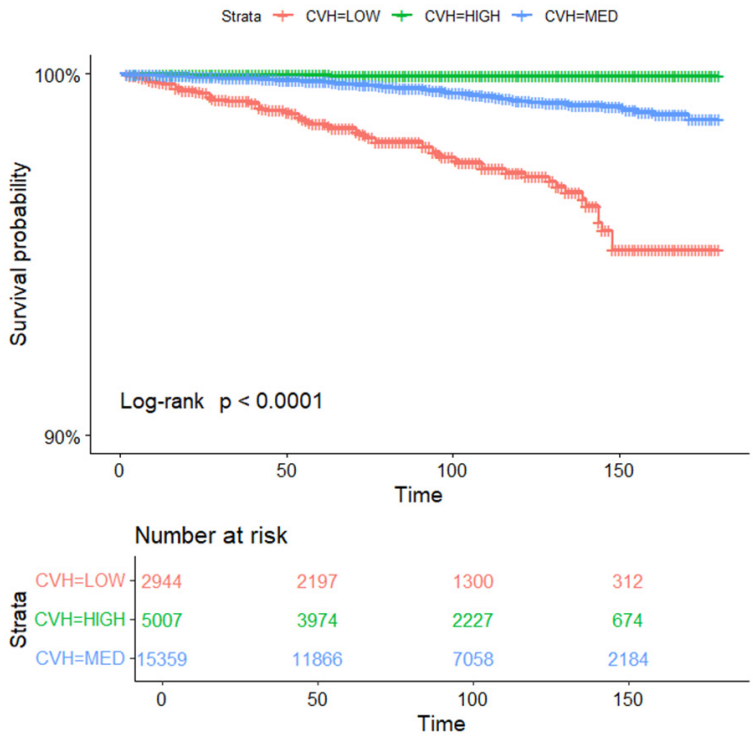

Figure 2. KM Curves for diabetes-related mortality in US adults with different CVH Levels. The Y-axis of the curve intercepts more than 60% of the portion.

tency in training and validation sets across analyses of the same marker, preventing variability in *P* values upon reanalysis [19]. To be comparable with the traditional CVH level proposed by AHA, two optimal cutoff values were selected to segment the data. The decision curve (DCA) was plotted to evaluate the clinical net benefit of the new and old models with an area higher than the NONE line (all samples were negative, all people did not get intervention) and the ALL line (all samples were positive, all people were given intervention). The DCA curve was drawn using the R package 'ggDCA'.

Results

Basic characteristics of participants

The mean age of the 23,310 participants involved in the analysis was 46.16 years (SD = 16.51), of which 51.0% were female and 41.5% were non-Hispanic white. These included 2,170 people with diabetes, 5,923 participants with pre-diabetes, and 15,217 participants who were normoglycemic. **Table 1** presents basic characteristics, total CVH scores, CVH levels, and mortality for different glycemic status groups. The mean total CVH score for individuals with diabetes was the lowest, at 53.69 (SD = 12.83); for participants with prediabetes, the mean total CVH score was 60.88 (SD = 12.58); and for those with normal blood glucose, the mean total CVH score was 71.57 (SD = 13.16). Among the three glycemic states, diabetics exhibited the highest diabetes-related mortality rate, which was 4.52%, and also had the highest cardiovascular mortality rate, at 3.09%. Individual CVH components score by glycemic status is shown in Table S3.

CVH and diabetes-related mortality

For U.S. adults across all glycemic statuses, there was a significant negative correlation between CVH and diabetes-related mortality (log-rank P < 0.001, **Figure 2**). Compared with low CVH levels, the risk of diabetes-related mortality decreased by 78.76% at medium CVH levels and 98.32% at high CVH levels. The risk of diabetes-related mortality decreased by 51.13% for every 10-point increase in the total CVH score (**Table 2**). After accounting for demographic characteristics, the previous results exhibited minimal variation.

Weight analysis of CVH components

There was a significant correlation among the components of CVH, with the correlation between blood glucose and blood pressure being the strongest (**Figure 3**). Further analysis by WQS regression model found that the mixed effect of CVH was significantly negatively correlated with diabetes-related mortality (95% CI: -5.4814 to -3.3723), and the correlation was still significant after adjusting for covariates (95% CI: -4.2378 to -1.7414). The top three CVH groups contributing to the mixed effect were blood glucose (64.6%), physical

Table 2. Association of cardiovascular health with diabetes-related mortality in U.S. adults

Order	Model 1		Model 2	
	HR	95% CI	HR	95% CI
CVH score	0.9309	0.9206, 0.9413	0.9460	0.9344, 0.9577
CVH level				
Low	Ref		Ref	
Moderate	0.2124	0.1530, 0.2949	0.3156	0.2257, 0.4411
High	0.0168	0.0041, 0.0687	0.0533	0.0129, 0.2207

Model 1, Unadjusted for covariates; Model 2, Adjusted for sex, age, race and ethnicity, marriage, educational levels, and family income.

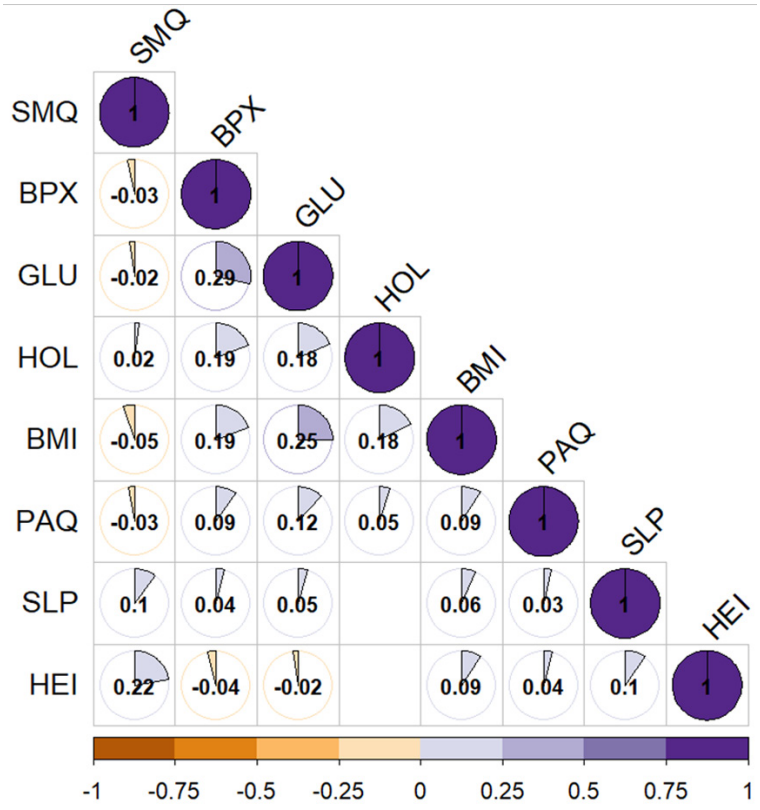

Figure 3. Heat map of correlation coefficient matrix for CVH Component. SMQ, Tobacco/nicotine exposure score; BPX, Blood pressure score; GLU, Blood glucose score; HOL, Blood lipid score; BMI, Body mass index score; PAQ, Physical activity score; SLP, Sleep health score; HEI, Healthy Eating Index score.

activity (26.1%), and blood lipids (4.9%), and the results did not change substantially after adjusting for covariates (**Table 3**).

Weight analysis of CVH components in blood glucose status subgroups

In the overall population, the contribution of blood glucose to diabetes-related mortality was more than 60%, and the diabetes-related mortality of people with different blood glucose statuses was also different ($P < 0.001$). Therefore, we further assessed the relationship between the mixed effect of CVH and diabetes-related mortality across different subgroups of the glycemic status population. Among them, only the WQS index of the diabetic group was significantly negatively correlated with the diabetes-related mortality (**Table 4**). In the normal blood glucose group and the pre-diabetic group, there appeared to also be a certain negative correlation between the mixed effect of CVH and the diabetes-related mortality, but the difference was not statistically significant. At the same time, we found that, different from the general population, the top three CVH components affecting diabetes-related mortality among diabetic patients were blood pressure (35.68%), tobacco/nicotine exposure (18.65%), and diet quality (18.49%) (**Figure 4**).

Weight-adjusted CVH score and mortality risk

The results of the WQS regression analysis showed that the contribution of each component of CVH to the diabetes-related mortality of diabetic patients was different. Therefore, we optimized the CVH total scoring system by adjusting the weights of each component based on their respective contributions to diabetes-related mortality in diabetic patients. Specifically, we significantly increased the weight ratios of blood pressure level, tobacco/nicotine exposure, diet quality, and blood glucose to 35.68%, 18.65%, 18.49%, and 11.12%, respectively, and moderately reduced the weight ratios of physical activity, blood lipid level, sleep quality, and BMI to

Table 3. WQS index and diabetes-related mortality in U.S. adults

Order	Model 1		Model 2	
	Component	Weight	Component	Weight
1	GLU	0.64633	GLU	0.63937
2	PAQ	0.26086	PAQ	0.25271
3	HOL	0.04870	BPX	0.05568
4	BPX	0.02053	HOL	0.03218
5	BMI	0.01152	HEI	0.00730
6	HEI	0.00715	SLP	0.00534
7	SLP	0.00388	BMI	0.00382
8	SMQ	0.00104	SMQ	0.00359

Model 1, Unadjusted for covariates; Model 2, Adjusted for sex, age, race and ethnicity, marriage, educational levels, and family income.

Table 4. WQS index for different glycemic states subgroups

	WQS index	95% CI
Diabetes	-0.6622	-1.2527, -0.0717
Prediabetes	-0.0642	-2.3113, 2.1829
Normal	-2.0071	-4.5435, 0.5292

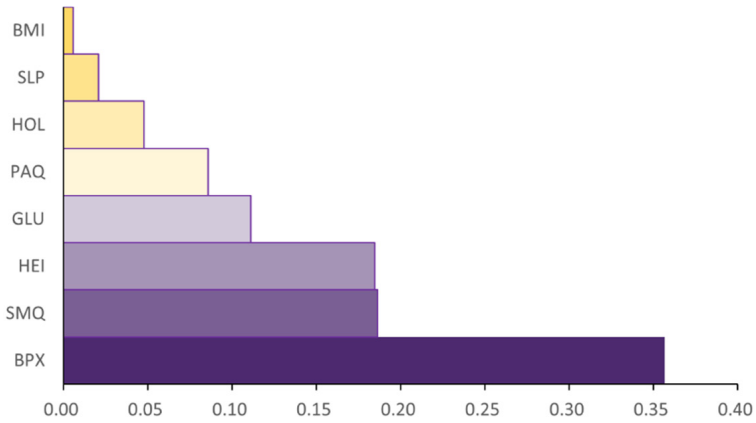

Figure 4. Weighting indices of CVH components in the diabetes group.

8.59%, 4.78%, 2.09%, and 0.60%, respectively (Table S4).

We assessed the relationships between the adjusted CVH score and diabetes-related mortality, cardiovascular death, and all-cause mortality among diabetic patients (**Table 5**). Firstly, a significant association was observed between corrected CVH scores and diabetes-related deaths, with a 26.26% decrease in the risk of such deaths for every 10-point decrement in CVH scores. Second, our analysis revealed a significant association between adjusted CVH scores and both the risk of cardiovascular mortality and the risk of all-cause mortality among diabetic patients. Specifically, for every 10-point increase in CVH scores, there was a notable 24.72% decrease in the risk of cardiovascular mortality and a similar 25.88% reduction in the risk of all-cause mortality. This finding underscores the significance of adjusting the CVH score to account for potential confounding factors in the context of diabetic patients, as the unadjusted original score failed to significantly predict cardiovascular death (HR = 0.9842, 95% CI: 0.9661 to 1.0030), whereas the adjusted score demonstrated a statistically significant association with reduced risk of cardiovascular death in this population (HR = 0.9720, 95% CI: 0.9573 to 0.9869).

Comparison of reclassified CVH level with original CVH level

Given that cardiovascular death represents the most common cause of mortality among diabetic patients [11], we opted to utilize cardiovascular death data as the primary outcome measure for delineating the novel CVH levels. We partitioned the cardiovascular death data of diabetic patients into two distinct subsets: a training set and a validation set. By analyzing the X-tile map, we found that 31.3 and 60.7 were the best nodes for cutting data (**Figure 5**). After rounding, 30 and 60 points were used as the new critical criteria for judging the CVH level of diabetic patients (CVH score < 30 points for low CVH level, 30-59 points for medium CVH level, 60 points for high CVH level).

We compared the predictive performance of the new CVH level with the original CVH level and discovered that the new CVH level exhibited a significantly higher clinical net benefit in

Table 5. Association of CVH scores with diabetes-related mortality, cardiovascular death, and all-cause mortality in diabetic patients

	Model 1		Model 2	
	HR	95% CI	HR	95% CI
Diabetes-related mortality				
Original CVH score	0.9733	0.9585,0.9883	0.9742	0.9587,0.9899
Adjusted CVH score	0.9700	0.9578,0.9823	0.9730	0.9634,0.9888
Cardiovascular death				
Original CVH score	0.9842	0.9661,1.0030	0.9862	0.9670,1.0057
Adjusted CVH score	0.9720	0.9573,0.9869	0.9791	0.9637,0.9948
All-cause mortality				
Original CVH score	0.9822	0.9731,0.9913	0.9806	0.9711,0.9902
Adjusted CVH score	0.9705	0.9631,0.9780	0.9758	0.9681,0.9836

Model 1, Unadjusted for covariates; Model 2, Adjusted for sex, age, race and ethnicity, marriage, educational levels, and family income.

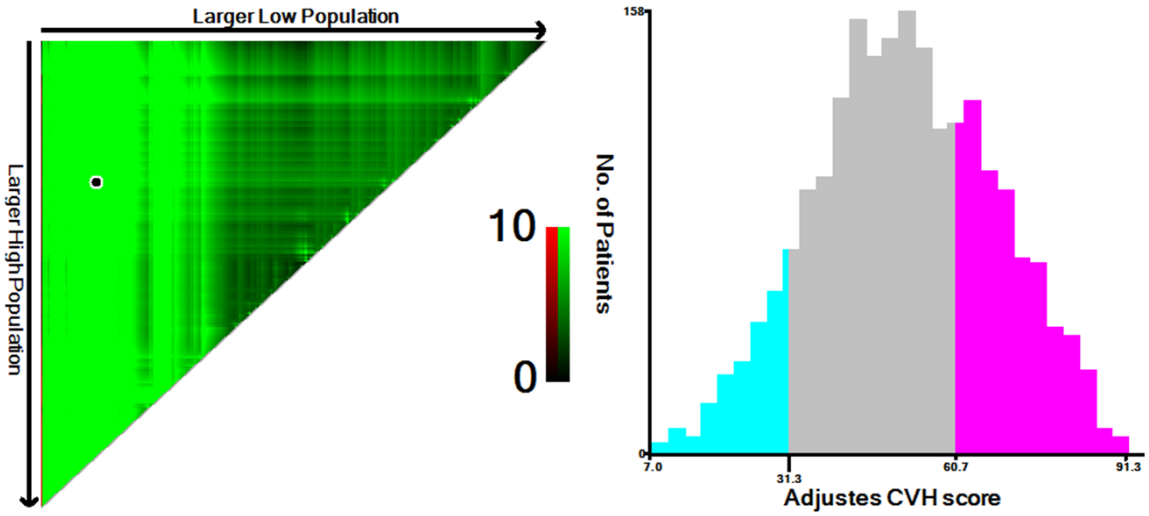

Figure 5. The survival Chi-Sq HiMidLo and histogram for adjusted CVH score.

predicting diabetes-related mortality (**Figure 6A**). We subsequently compared the predictive efficacy of the new CVH level with that of the original CVH level for both cardiovascular death and all-cause mortality. Our findings revealed that the new CVH level demonstrated a significantly higher net clinical benefit compared to the original CVH level, in terms of both cardiovascular death and all-cause mortality reduction (**Figure 6B**, **6C**). Furthermore, the goodness-of-fit of the Cox proportional hazards regression model incorporating the new CVH level was significantly superior to that incorporating the original CVH level, in terms of predicting diabetes-related mortality, cardiovascular death, and all-cause mortality (**Table 6**).

Discussion

This study found that there is a significant negative correlation between CVH defined by LE8 and diabetes-related mortality in American adults, and this negative correlation mainly exists in diabetic patients. For the whole population, the most important CVH component affecting the diabetes-related mortality is blood glucose, while for diabetic patients, the most important CVH component affecting the diabetes-related mortality is blood pressure. In comparison to the CVH score and CVH level defined by the AHA, our weighted adjusted CVH score and CVH level exhibited a stronger predictive capability for assessing diabetes-related mor-

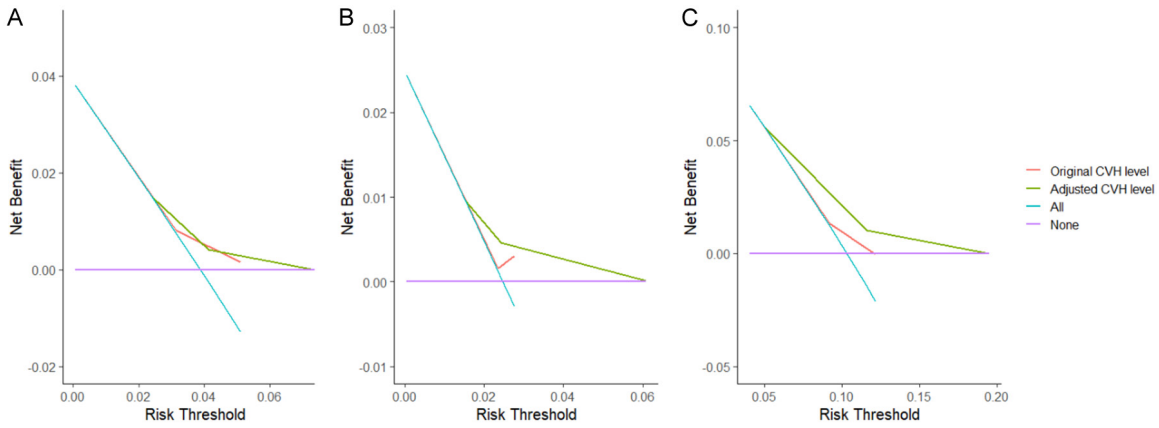

Figure 6. Clinical decision curves for the risk of diabetes-related mortality, cardiovascular death, and all-cause mortality in diabetic patients. A: Clinical decision curves for the risk of diabetes-related mortality; B: Clinical decision curves for the risk of cardiovascular mortality; C: Clinical decision curves for the risk of cardiovascular mortality; ALL: Intervention applied to all patients; None: No intervention for any patients.

Table 6. C-index comparison of COX models with adjusted CVH level to original CVH level

	Original CVH level		Adjusted CVH level	
	Concordance	SE	Concordance	SE
Diabetes-related mortality	0.591	0.027	0.595	0.027
Cardiovascular death	0.559	0.034	0.605	0.037
All-cause mortality	0.543	0.017	0.604	0.015

tality risk, cardiovascular death risk, and all-cause mortality among diabetic patients.

To the best of our knowledge, this is the first study to assess the association between LE8-defined CVH and diabetes-related mortality in U.S. adults. The existing results are consistent with previous studies on healthy lifestyles and mortality in patients with diabetes. Sun, Y. et al.'s prospective study based on a UK biobank found that for patients with type 2 diabetes (T2D), maintaining an ideal LE8 score can not only significantly reduce the risk of premature mortality, but also prolong life expectancy. In contrast, the benefits are smaller in non-T2D populations [20]. Long-term follow-up results of the China Daqing Diabetes Prevention Study (CDQDPS), which began in 1986, showed that the LE8 score of T2D patients was significantly lower than that of non-T2D patients. Diet and exercise interventions significantly reduced the incidence of diabetes, cardiovascular death, and all-cause mortality in people with impaired glucose tolerance (IGT), and the average life expectancy of the lifestyle intervention group was 1.44 years longer than that of the control group [21]. At present, only a few studies have evaluated the association between CVH or healthy lifestyle and diabetes-related mortality, and these studies have not yet paid attention to the contribution of each CVH component to diabetes-related mortality.

In this study, the contribution of eight CVH components to diabetes-related mortality was evaluated by the WQS regression model. This is a commonly used analysis method in environmental hygiene that quantifies the collective impact of all CVH components on diabetes-related mortality through the calculation of a weighted linear index. Additionally, the corresponding weight assigned to each component indicates its individual contribution to the overall effect [22]. We found that the contribution of CVH components in diabetic patients was significantly different from that in the whole population. Blood glucose was the most important CVH component affecting diabetes-related mortality in the whole population (64.6%), while blood pressure was the most important CVH component affecting diabetes-related mortality in diabetic patients (35.7%). It is worth noting that the contribution of diet quality was only 0.7% in the whole population, but in the diabetes group, the contribution of diet quality reached 18.5%, which was the top three CVH components. The importance of diet quality for glycemic control has been frequently mentioned in previous studies [23-26]. Data from

the Nurses' Health Study (NHS) and the Health Professionals Follow-up Study (HPFS) also showed a negative correlation between the individual diet score (HEI-2015) and all-cause mortality [27]. However, no study has yet found an association between HEI-2015 and diabetes-related mortality.

In summary, following the alteration in health status, the contribution of each CVH component to mortality has undergone significant changes, rendering the CVH standard originally devised for the general population insufficient for accurately predicting the risk of mortality among diabetic patients. Although there was a significant association between the CVH score defined by AHA and the risk of all-cause mortality in diabetic patients, no significant association was found between the CVH score defined by AHA and the risk of cardiovascular death. Therefore, we re-adjusted the calculation method of the CVH score, taking into account the contribution weight of each CVH component to diabetes-related mortality in diabetic patients, and found a significant correlation between the revised CVH score and the risk of cardiovascular death among this patient population.

The primary strengths of this study encompass the utilization of the LE8 system to define CVH, the rigorous examination of the relationships between both CVH score and CVH level with diabetes-related mortality, and the innovative redefinition of CVH through weight adjustment, specifically tailored for diabetic patients, ultimately providing a feasible and actionable solution for clinical practice. However, this study also has several limitations. First, the average age of the study population was 46 years old, and this study used NHANS data from 2005 to 2018. The longest follow-up time was 180 months, and the number of cardiovascular death during the follow-up period was less. This may be the reason why there is no significant correlation between the original CVH score and cardiovascular death. Secondly, indicators such as diet quality, physical activity, tobacco/nicotine exposure, and sleep health are all obtained through participants' self-reports, which may cause results to introduce recall bias. Finally, although multivariate adjustments have been made to control potential confounding factors, there may still be residual or unmeasured confounding variables that affect the accuracy of the estimation.

Disclosure of conflict of interest

None.

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Table S1. Life's simple 7 vs life's essential 8

	Life's Simple 7	Life's Essential 8
Components	Dietary quality, Physical activity, Tobacco/nicotine exposure, Body mass index, Blood glucose, Blood lipid, Blood pressure.	Dietary quality, Physical activity, Tobacco/nicotine exposure, Body mass index, Blood glucose, Blood lipid, Blood pressure, Sleep health.
Indicator assessment	Each indicator is categorized into low, medium and high levels.	Each indicator is scored at five or more levels.
Scoring range	Individual CVH indicator scores range from 0-2; Total CVH score range 0-14 points.	Individual CVH indicator scores range from 0-100; Total CVH score range 0-100 points.
Specific definitions		
Dietary quality	Only five components were assessed: fruits and vegetables, fish, fiber-rich whole grains, sodium, and sugar-sweetened beverages.	Assessed using the full Dietary Quality Scoring System (HEI-2015 was used for this study).
Tobacco/nicotine exposure	Excluding secondhand smoke exposure.	Including secondhand smoke exposure.
Blood lipid	Assessed using total lipoprotein cholesterol.	Evaluation using non-HDL.
Blood glucose	Excluding glycosylated hemoglobin.	Includes glycosylated hemoglobin.

Table S2. The scoring criteria of life's essential 8

CVH components	Measurement methods	Score	Standard measurement
Dietary quality	Dietary intake consistent with the HEI-2015 dietary pattern was assessed by two 24-hour dietary recalls.	100	Above the 95th percentile
		80	75th-94th percentiles
		50	50th-74th percentiles
		25	25th-49th percentile
		0	1-24th percentile
Physical activity	Self-reported minutes of moderate or vigorous exercise per week.	100	≥ 150 min
		90	120-149 min
		80	90-119 min
		60	60-89 min
		40	30-59 min
		20	1-29 min
		0	0 min
Tobacco/nicotine exposure	Self-reported use of cigarettes or exposure to secondhand smoke.	100	Never smoked
		75	Ever smoked, quit smoking ≥ 5 years
		50	Ever smoked, quit smoking 1-5 years
		25	Ever smoked, quit smoking < 1 years
		0	Currently still smoking
	If there is an active indoor smoker in the home, subtract 20 points.		

Sleep health	Self-reported average number of hours of sleep per night.	100	7-9 hours
		90	9-10 hours
		70	6-7 hours
		40	5-6/≥ 10 hours
		20	4-5 hours
		0	< 4 hours
Body mass index	Body Mass Index (BMI) is calculated by dividing weight by the square of height based on standardized height and weight measurements.	100	< 25 kg/m^2
		70	25.0-29.9 kg/m^2
		30	30.0-34.9 kg/m^2
		15	35.0-39.9 kg/m^2
		0	≥ 40.0 kg/m^2
Blood lipid	Non-HDL cholesterol = total cholesterol - HDL sterols.	100	< 130 mg/dL
		60	130-159 mg/dL
		40	160-189 mg/dL
		20	190-219 mg/dL
		0	≥ 220 mg/dL
	Subtract 20 points if the level is treated with medication.		
Blood glucose	Glycated hemoglobin (HbA1c) was measured by high performance liquid chromatography (HPLC); Fasting blood glucose (FBG) was measured by standard methods.	100	No history of diabetes and FBG < 100 mg/dL (or HbA1c < 5.7%)
		60	No history of diabetes and FBG of 100-125 mg/dL (or HbA1c 5.7-6.4%)
		40	Diabetic patients with HbA1c < 7.0%
		30	Diabetic patients with HbA1c 7.0-7.9%
		20	Diabetic patients with HbA1c 8.0-8.9%
		10	Diabetic patients with HbA1c 9.0-9.9%
		0	Diabetic patients with HbA1c ≥ 10.0%
Blood pressure	The average of all available blood pressure measurements was used to calculate systolic and diastolic blood pressure.	100	< 120/< 80 mm Hg
		75	120-129/< 80 mm Hg
		50	130-139/80-89 mm Hg
		25	140-159/90-99 mm Hg
		0	≥ 160/≥ 100 mm Hg
	Subtract 20 points if the level is treated with medication.		

Table S3. Individual CVH components score by glycemic status

	Normal (N = 15217)	Prediabetes (N = 5923)	Diabetes (N = 2170)
Healthy Eating Index score, mean (SD)	41.87 (32.07)	43.78 (31.96)	44.12 (31.93)
Physical activity score, mean (SD)	78.38 (37.02)	70.54 (41.55)	63.34 (44.03)
Tobacco/nicotine exposure score, mean (SD)	67.54 (24.45)	68.35 (40.73)	71.22 (38.55)
Sleep health score, mean (SD)	82.31 (24.68)	79.79 (26.46)	79.00 (26.55)
Body mass index score, mean (SD)	66.07 (32.45)	51.85 (33.47)	41.67 (32.21)
Blood lipid score, mean (SD)	69.16 (30.12)	57.32 (30.76)	56.14 (32.10)
Blood glucose score, mean (SD)	92.29 (16.21)	57.78 (6.93)	25.24 (14.13)
Blood pressure score, mean (SD)	74.97 (30.95)	57.30 (33.89)	48.78 (33.69)

Table S4. CVH scores adjusted for proportionate contribution to diabetes-related mortality

CVH components	Adjusted CVH score
Dietary quality	original CVH score*0.18486
Physical activity	original CVH score*0.08593
Tobacco/nicotine exposure	original CVH score*0.18646
Sleep health	original CVH score*0.02093
Body mass index	original CVH score*0.00595
Blood lipid	original CVH score*0.04779
Blood glucose	original CVH score*0.11124
Blood pressure	original CVH score*0.35684