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RESEARCH

Associations of healthy lifestyle and family income to poverty ratio with all-cause mortality among people with prediabetes and diabetes: a prospective cohort study

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Abstract

Background Family income to poverty ratio (PIR) may have independent effects on diet and lifestyle factors and the development of prediabetes and diabetes, as well as on mortality. It is unclear how the protective effect of a healthy lifestyle against death differs between individuals with different glucose metabolic profiles and whether PIR mediates this effect. This study aimed to explore whether healthy lifestyle and family PIR reduced the risk of all-cause mortality in participants with different metabolic status and the mediating role of PIR.

Subjects and methods In total, 21,411 participants from the 2001–2018 National Health and Nutrition Examination Survey (NHANES) and follow-up until 2019 were included. The weighted healthy lifestyle score was constructed based on smoking, alcohol consumption, physical activity, diet (HEI-2015), and body mass index. Generalized linear regression models were used to analyze the association between healthy lifestyle, PIR, and all-cause mortality. Cox proportional hazard models were used to calculate hazard ratios (HRs) and 95% confidence intervals, Kaplan-Meier survival curve was used to analyze the all-cause mortality associated with PIR and lifestyle. Furthermore, the mediation proportion of PIR in all-cause mortality attributed to healthy lifestyle was analyzed among participants with normal glucose regulation, prediabetes, or diabetes after multivariable adjustment.

Results There were significant differences in healthy lifestyle and PIR among people with normal glucose regulation, prediabetes and diabetes. During a mean follow-up of 92 months, participants with prediabetes or diabetes were also likely to have a higher mortality rate, respectively 583 (8.3%) and 263 (12.7%). More than 2 healthy lifestyles were associated with 42% (HR, 0.58; 95% CI, 0.35–0.95) to 76% (HR, 0.24; 95% CI, 0.12–0.44) reduced risk of all-cause mortality among participants with prediabetes, but among those with diabetes, who had ≥ 4 healthy lifestyles were associated with 72% reduced risk of all-cause mortality (HR, 0.28; 95% CI, 0.09–0.90). The middle and high PIR were associated with at least a 37% (HR, 0.63; 95% CI, 0.47–0.83) to 65% (HR, 0.35; 95% CI, 0.18–0.68) lower risk of all-cause mortality in participants with prediabetes and diabetes. Furthermore, PIR mediated 5.81-14.93% and 7.72-10.10% of the association between healthy lifestyle and all-cause mortality among normal glucose regulation and prediabetic participants, respectively. However, the mediating effect of PIR was not significant among diabetic participants.

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Conclusions Our findings highlight the importance of promoting adherence to a healthy lifestyle and improving PIR in prediabetic patients to reduce the risk of all-cause mortality, and the protective effect is more significant with more healthy lifestyles and higher PIR. This study can help clinicians and health systems develop more targeted treatments for people with different metabolic levels.

Keywords NHANES, Healthy lifestyle, Mortality, Prediabetic

Introduction

The epidemic of diabetes and prediabetes has become a public health problem worldwide. These chronic metabolic diseases are associated with a number of serious health problems, including cardiovascular disease, kidney disease, and increased all-cause mortality [1]. According to the International Diabetes Federation, diabetes is a global public health crisis that affects more than 500 million adults worldwide, placing a heavy health and economic burden on individuals, families and health systems [2, 3]. Therefore, it is critical to identify effective strategies to prevent and delay the development of death and complications in people with diabetes and prediabetes.

The American Diabetes Association guidelines also emphasize that in addition to medications to control blood sugar, caregivers and patients should focus on optimizing lifestyle behaviors to improve diabetes care and prevent higher mortality [4]. Previous research has shown that adopting a healthy lifestyle, such as a healthy diet, moderate exercise, smoking cessation and limiting alcohol intake, is essential to prevent the onset of diabetes and reduce the risk of diabetes complications [5–7]. However, to the best of our knowledge, the extent to which multiple lifestyle factors are jointly associated with the occurrence of death in people with diabetes or prediabetes has not been quantified. This could have significant public health implications for translating epidemiological findings into meaningful public health actions. In addition, the family income to poverty ratio (PIR) is also believed to be associated with diabetes. Low income and high rates of poverty are associated with a higher risk of diabetes and poor diabetes management [8, 9]. Poverty and income as such are very poor indicators of mortality among populations that are in transition from poverty to affluence [1, 10–12]. People may be poor with lower income but have greater life expectancy, like in Kerala, India. Moreover, education, in particular health education, has been found to be the most important determinant of mortality [11]. Similarly, people may have increased income but greater mortality due to increased intake of western type ready prepared foods and use of automobiles, causing lower physical activity and greater mortality, such as in North India [12]. However, the effects of a healthy lifestyle and PIR on all-cause mortality in the population among different glucose metabolic states, especially in individuals with prediabetes or diabetes, are not fully understood. Whether and to what extent PIR mediate the association between healthy lifestyle behaviors and death in patients with different glucose metabolism is unclear.

To elucidate the potential association of healthy lifestyle with all-cause mortality in patients with different glucose metabolism, this study compared the combined association of multiple lifestyle behaviors in normal glucose regulation, prediabetic and diabetic patients, including healthy diet, current non-smoking, low-to-moderate alcohol consumption, adequate physical activity, no overweight/obesity associated with all-cause mortality. In addition, this study comprehensively evaluated the effects of PIR on mediating the relationship between lifestyle and all-cause mortality and provided the basis for guiding public health policy in developing personalized health interventions and improving the quality of life among these patients with dysglycemia.

Subjects and methods

Data source and sample design

The National Health and Nutrition Examination Survey (NHANES) is an ongoing survey of the national population of the United States (US) that employs a complex, multistage and probabilistic sampling technique to provide a plethora of information on nutrition and health of the US population. The NHANES is a major program of the National Center for Health Statistics (NCHS). It was designed to assess the health and nutritional status of adults and children in the US. Details of recruitment, procedures, population characteristics, and study design for NHANES are provided through the Centers for Disease Control and Prevention [13]. All study procedures were authorized by the Ethical Review Board of the National Center for Health Statistics before data collection, and all participants gave their signed informed consent.

Population

The current analysis included 91,351 patients enrolled in the NHANES (2001–2018) survey, including patients with diagnosable diabetes-related data, complete PIR data, and follow-up mortality data until 2019 ($N=22{,}314$). Patients with cardiovascular disease who had no lifestyle factors and had heart failure ($n=881$), coronary heart disease ($n=1{,}136$), angina pectoris ($n=696$), stroke ($n=1{,}024$) at baseline were excluded; Patients with liver disease ($n=1{,}053$), kidney failure ($n=832$), and cancer (*n*=2,711) were excluded from the analysis (*N*=5,898). Overall, 21,411 subjects from NHANES in the US were included. (Fig. 1)

Assessment of prediabetes and diabetes

The baseline of prediabetes and diabetes was defined according to the 2021 American Diabetes Association criteria [14]. Prediabetes was defined as fasting plasma glucose levels between 100.90 mg/dL and 124.32 mg/dL, 2-hour plasma glucose levels between 140.54 mg/dL and 198.20 mg/dL, or HbA1c concentrations between 5.7% and 6.4% in participants without a prior diagnosis of diabetes. This study focused on type 2 diabetes. Diabetes was defined as a fasting plasma glucose level of at least 126.13 mg/dL, a 2-hour plasma glucose level of at least 200 mg/dL, an HbA1c level of at least 6.5%, or a previous self-reported diagnosis by health care professionals.

Measurements of lifestyle behaviors

All information on the lifestyles of participants was obtained through a self-reported structured questionnaire and 24-hour dietary recall, including smoking, alcohol consumption, physical activity, body mass index (BMI), and diet. We assigned a score of one to a healthy lifestyle and zero to an unhealthy lifestyle [15, 16]. To better reflect the effect of each healthy lifestyle factor on the outcome, we constructed a healthy lifestyle score by calculating a weighted healthy lifestyle score. Non-smoking was defined in the questionnaire as smoking less than 100 cigarettes in a lifetime [17]. No alcohol consumption was defined as the current frequency and amount of alcohol consumption of less than 14 g of alcohol per day for females and less than 28 g for males [18]. Physical activity was defined as moderate and vigorous exercise [19]. A healthy BMI was defined as <24. Diet quality was obtained by the 24-hour dietary recall and evaluated using the Healthy Eating Index (HEI) score. The HEI-2015 is a standard developed by the US Department of Agriculture to assess dietary quality [20]. Based on the recommendations of the Dietary Guidelines for Americans, HEI-2015 can assesse whether the dietary structure of an individual or a group meets the criteria for a healthy diet. The HEI includes 13 components, which are fruits, vegetables, whole grains, dairy products, eggs, protein foods, proportion of fatty acids, intake of saturated fatty acids, solid fats and sugars, intake of sodium, and intake of alcoholic beverages. Each component has a corresponding rating scale, with a total score of 100 points. A higher score represents a dietary pattern more consistent with the criteria for a healthy diet. Supplemental Table 1 provides structural details of HEI-2015, which reflects overall dietary quality according to contemporary dietary guidelines. A healthy diet was defined as a healthy eating index in the top two quintiles of the distribution. To avoid extreme groups, which were divided into 0, 1, 2, 3, and ≥4 according to the number of healthy lifestyles.

Covariates

PIR was calculated by dividing family (or individual) income by poverty guidelines specific to the survey year

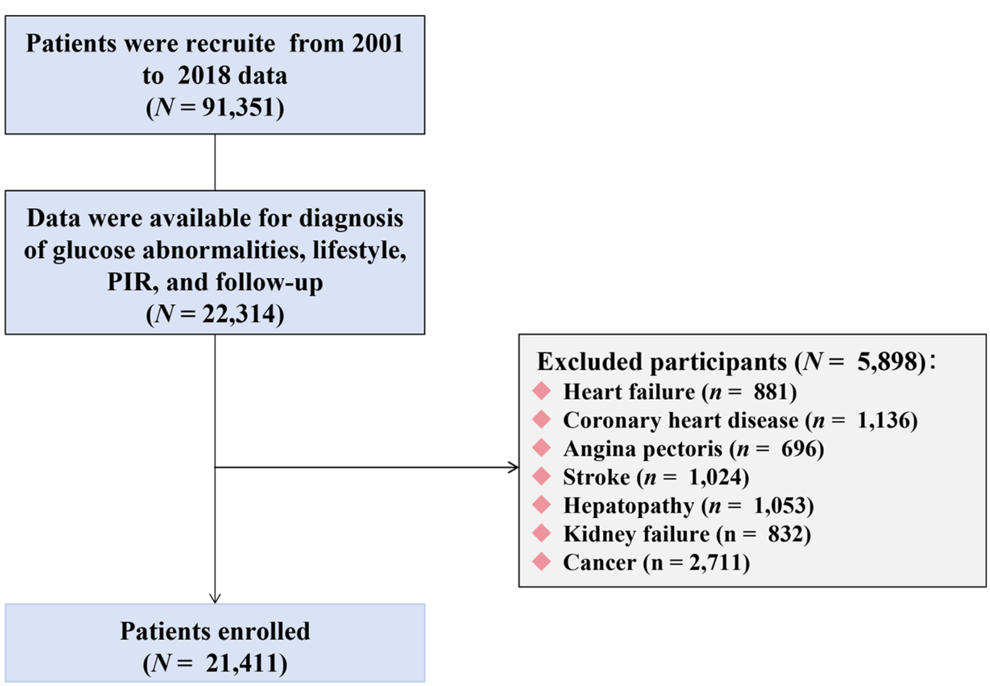

Fig. 1 Flow chart of the screening of eligible participants

and used to measure socioeconomic status. And since the income threshold is updated annually based on inflation and family size, we grouped participants according to the PIR: low household income (PIR ≤ 1), middle household income (PIR = 1–4), and high household income (PIR ≥ 4) [21]. Race was divided into Mexican American, other Hispanic, non-Hispanic white, non-Hispanic black, and other races (including multi-racial). Education was categorized into less than high school, high school, and more than high school. Marital was categorized into married/widowed, divorced/separated, and never married/living with partner.

Other covariates included the laboratory data. Blood specimens were processed, stored, and transported to the Fairview Medical Center Laboratory at the University of Minnesota (Minneapolis, MN, USA) for analysis. The staff were well trained, and the NCHS developed and distributed a quality control protocol to each NHANES contract laboratory. Hyperlipidemia was defined as TC ≥ 6.2 mmol/L (240 mg/dL), TG ≥ 2.3 mmol/L (200 mg/dL), LDL-C ≥ 4.1 mmol/L (160 mg/dL), or HDL-C ≤ 1.0 mmol/L (40 mg/dL) [22, 23]. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were averaged over four measurements by experienced technicians at the heart level using automatic blood pressure monitors. SBP ≥ 130 mmHg or DBP ≥ 80 mmHg was defined as hypertension [24].

Outcome ascertainment

The NCHS links data collected by population surveys to death certificate records in the National Death Index (NDI). The outcomes were classified using ICD-9 and ICD-10 (International Classification of Diseases, 9th and 10th revisions, respectively). In NHANES, the number of deaths was obtained through the NDI as of December 31, 2019. For more information on accessing the restricted use linked mortality files, please refer to the official website (https://www.cdc.gov/nchs/data-linkage). This study defined the outcome as all-cause mortality (heart disease, cancer, chronic lower respiratory disease, unintentional injuries, and cerebrovascular diseases).

Statistical analysis

To estimate appropriate variance and statistics representative of US adults, our analysis in US NHANES considered the oversampling, stratification, and clustering according to the NHANES statistical analysis guideline. Baseline characteristics of participants with normal glucose regulation, prediabetes, and diabetes were summarized as means with standard deviation for continuous variables and percentages for categorical variables. The Chi-square test, ANOVA, and Kruskal–Wallis test were used to compare the distribution of baseline characteristics among the different glucose metabolism states. Cox proportional hazard models were used to calculate hazard ratios (HRs) and 95% confidence intervals (CI) for all-cause mortality associated with PIR and lifestyle, with multivariable adjustment for age, sex, race, marital status, educational level, SBP, DBP, TC, TG, HDL-C, and LDL-C. Furthermore, the mediation proportion of PIR in all-cause mortality attributed to a healthy lifestyle was analyzed among participants with normal glucose regulation, prediabetes or diabetes after multivariable adjustment.

To test the robustness and potential variations in different subgroups, we repeated all analyses stratified by gender (male and female), age groups (<60 and ≥60) defined as elders by the World Health Organization [25]), blood lipid (normal and dyslipidemia), and blood pressure (normal and hypertension) to examine the association between lifestyle and all-cause mortality risk among participants with normal glucose regulation, prediabetes or diabetes. All analyses were performed using R studio and SPSS 24.0 (IBM Corp, New York, NY, USA).

Results

Baseline characteristics

Baseline characteristics of the study participants according to glucose metabolism status are shown in Table 1. A total of 21,411 participants from 91,351 participants of the 2001–2018 NHANES were included in the analysis. 12,288 (57.39%) had normal glucose regulation, 7,054 (32.95%) had prediabetes, and 2,069 (9.66%) had diabetes. The mean age was 44 years. Compared to participants with normal glucose regulation, participants with prediabetes or diabetes were older, had higher proportions of female, Mexican American, and other Hispanics, had lower levels of educational attainment, were more likely to have low and middle household income, had poorer metabolic profiles (higher TC, TG, LDL-C, SBP, DBP, lower HDL-C), high proportions of hypertension and hyperlipemia, and less number of health lifestyles. During a mean follow-up of 92 months, participants with prediabetes or diabetes were also likely to have a higher mortality rate, respectively, 583 (8.3%) and 263 (12.7%).

All-cause mortality in relation to the number of healthy lifestyles among participants with normal glucose regulation, prediabetes, and diabetes

As shown in Table 2, after multivariate adjustment, participants who had a number ≥ 4 of these healthy lifestyles significantly lowered risk for all-cause mortality; respectively, the risk is reduced by 70% (HR, 0.30; 95% CI, 0.13–0.68), 76% (HR, 0.24; 95% CI, 0.12–0.44), and 72% (HR, 0.28; 95% CI, 0.09–0.90) among participants with normal glucose regulation, prediabetes, and diabetes. Kaplan-Meier curves showed improved survival with

Table 1 Baseline characteristics of participants with normal glucose regulation, prediabetes, and diabetes

Variable	Overall	Normal glucose regulation	Prediabetes	Diabetes	*P*
Participants, n (%)	21411	12288 (57.39)	7054(32.95)	2069(9.66)	
Age (median [IQR])	44.0 [31.0, 59.0]	37.0 [27.0, 50.0]	59.0 [48.0, 67.0]	53.0 [40.0, 64.0]	< 0.001
Age < 60year	16159 (75.5)	10594 (86.2)	1072 (51.8)	4493 (63.7)	< 0.001
Age ≥ 60year	5252 (24.5)	1694 (13.8)	997 (48.2)	2561 (36.3)	
Gender, **n (%)**					< 0.001
Female	10149 (47.4)	5490 (44.7)	3640 (51.6)	1019 (49.3)	
Male	11262 (52.6)	6798 (55.3)	3414 (48.4)	1050 (50.7)	
Race, **n (%)**					< 0.001
Mexican American	3476 (16.2)	1868 (15.2)	1178 (16.7)	430 (20.8)	
Other Hispanic	1943 (9.1)	1067 (8.7)	668 (9.5)	208 (10.1)	
Non-Hispanic White	8993 (42.0)	5665 (46.1)	2719 (38.5)	609 (29.4)	
Non-Hispanic Black	4694 (21.9)	2342 (19.1)	1726 (24.5)	626 (30.3)	
Other Race - Including Multi-Racial	2305 (10.8)	1346 (11.0)	763 (10.8)	196 (9.5)	
Education, **n (%)**					< 0.001
Less than high school	4489 (21.3)	2089 (17.5)	1743 (24.8)	657 (31.9)	
High school	4811 (22.9)	2601 (21.8)	1736 (24.7)	474 (23.0)	
More than high school	11751 (55.8)	7267 (60.8)	3553 (50.5)	931 (45.2)	
Marital, **n (%)**					< 0.001
Married/Widowed	12065 (57.3)	6314 (52.8)	4387 (62.4)	1364 (66.1)	
Divorced/Separated	2787 (13.2)	1332 (11.1)	1106 (15.7)	349 (16.9)	
Never married/Living with partner	6198 (29.4)	4309 (36.0)	1539 (21.9)	350 (17.0)	
BMI (median [IQR])	27.98 [24.22, 32.59]	26.62 [23.27, 30.92]	29.20 [25.75, 33.93]	31.60 [27.55, 36.70]	< 0.001
TC (median [IQR])	4.94 [4.29, 5.66]	4.86 [4.22, 5.56]	5.09 [4.42, 5.79]	4.86 [4.14, 5.66]	< 0.001
TG (median [IQR])	1.33 [0.89, 2.08]	1.23 [0.81, 1.91]	1.40 [0.97, 2.14]	1.77 [1.20, 2.69]	< 0.001
HDL-C (median [IQR])	1.32 [1.09, 1.60]	1.37 [1.11, 1.66]	1.27 [1.06, 1.55]	1.19 [1.01, 1.45]	< 0.001
LDL-C (median [IQR])	2.90 [2.33, 3.54]	2.79 [2.25, 3.41]	3.03 [2.46, 3.65]	2.74 [2.10, 3.42]	< 0.001
SBP (median [IQR])	119.33 [110.00, 131.33]	116.00 [107.33, 126.00]	124.00 [114.67, 136.00]	128.67 [118.00, 143.33]	< 0.001
DBP (median [IQR])	70.67 [63.33, 78.00]	70.00 [62.67, 76.67]	72.00 [64.67, 79.33]	71.33 [63.33, 79.33]	< 0.001
Glucose (median [IQR])	5.50 [5.11, 6.00]	5.16 [4.88, 5.38]	5.83 [5.61, 6.16]	8.33 [7.04, 10.94]	< 0.001
HbA1c (median [IQR])	5.50 [5.20, 5.80]	5.30 [5.00, 5.40]	5.80 [5.60, 6.00]	7.30 [6.70, 8.70]	< 0.001
HEI-2015 (median [IQR])	50.08 [42.27, 58.92]	49.67 [41.88, 58.65]	50.41 [42.59, 59.11]	51.23 [43.36, 59.44]	< 0.001
Hypertension (%)	6079 (28.4)	2239 (18.2)	2637 (37.4)	1203 (58.1)	< 0.001
Hyperlipemia (%)	7368 (34.4)	3608 (29.4)	2787 (39.5)	973 (47.0)	< 0.001
All-cause Mortality, **n (%)**	1340 (6.3)	494 (4.0)	583 (8.3)	263 (12.7)	< 0.001
PIR (median [IQR])	2.22 [1.14, 4.19]	2.33 [1.16, 4.34]	2.16 [1.16, 4.12]	1.91 [1.06, 3.56]	< 0.001
PIR, **n (%)**					< 0.001
Low household income	4395 (20.5)	2517 (20.5)	1401 (19.9)	477 (23.1)	
Middle household income	11258 (52.6)	6293 (51.2)	3798 (53.8)	1167 (56.4)	
High household income	5758 (26.9)	3478 (28.3)	1855 (26.3)	425 (20.5)	
Low-to-moderate alcohol drinking, n (%)	10372 (48.4)	6656 (54.2)	2534 (35.9)	1182 (57.1)	< 0.001
Healthy diet, n (%)	8567 (40.0)	4796 (39.0)	2876 (40.8)	895 (43.3)	0.003
Current nonsmoking, n (%)	12635 (59.0)	7638 (62.2)	3868 (54.8)	1129 (54.6)	< 0.001
Adequate physical activity, n (%)	9921 (46.3)	5959 (48.5)	3191 (45.2)	771 (37.3)	< 0.001
No overweight/obesity, n (%)	16403 (76.6)	8525 (69.4)	5981 (84.8)	1897 (91.7)	< 0.001
Number of healthy lifestyle, **n (%)**					< 0.001
0	361 (1.7)	233 (1.9)	114 (1.6)	14 (0.7)	
1	2357 (11.0)	1254 (10.2)	910 (12.9)	193 (9.3)	
2	6261 (29.2)	3536 (28.8)	2167 (30.7)	558 (27.0)	
3	7499 (35.0)	4310 (35.1)	2452 (34.8)	737 (35.6)	
≥4	4933 (23.0)	2955 (24.0)	1411 (20.0)	567 (27.4)	

Data are presented as median (interquartile Range) or number (proportion, %)

SBP: systolic blood pressure, DBP: diastolic blood pressure, FPG: fasting plasma glucose, TC: total cholesterol, TG: triglycerides, HDL-C: high-density lipoprotein cholesterol, LDL-C: low-density lipoprotein cholesterol, HbA1c: glycated haemoglobin, PIR: income to poverty ratio, IQR: interquartile range

Table 2 Hazard ratio (95% CI) of healthy lifestyle and all-cause mortality among participants with normal glucose regulation, prediabetes or diabetes

Glucose metabolic states	Number of healthy lifestyle	Model 1		Model 2		Model 3	
		HR(95CI%)	*P*	HR(95CI%)	*P*	HR(95CI%)	*P*
Normal Glucose Regulation	0	ref		ref		ref	
	1	0.84(0.53–1.36)	0.483	1.04(0.65–1.67)	0.88	0.77(0.35–1.70)	0.52
	2	0.43(0.27–0.68)	< 0.001	0.62(0.39–0.98)	0.04	0.55(0.26–1.16)	0.12
	3	0.44(0.28–0.70)	< 0.001	0.57(0.36–0.89)	0.02	0.50(0.24–1.05)	0.07
	≥ 4	0.31(0.19–0.50)	< 0.001	0.38(0.24–0.61)	< 0.001	0.30(0.13–0.68)	< 0.001
Prediabetes	0	ref		ref		ref	
	1	0.73(0.48–1.09)	0.119	0.84(0.56–1.26)	0.4	0.66(0.39–1.10)	0.11
	2	0.43(0.29–0.64)	< 0.001	0.63(0.42–0.94)	0.02	0.58(0.35–0.95)	0.03
	3	0.26(0.17–0.39)	< 0.001	0.44(0.29–0.66)	< 0.001	0.45(0.27–0.75)	< 0.001
	≥ 4	0.13(0.08–0.20)	< 0.001	0.31(0.19–0.49)	< 0.001	0.24(0.12–0.44)	< 0.001
Diabetes	0	ref		ref		ref	
	1	0.50(0.21–1.19)	0.117	0.60(0.25–1.43)	0.25	0.72(0.23–2.26)	0.57
	2	0.42(0.18–0.95)	0.038	0.54(0.23–1.23)	0.14	0.66(0.23–1.94)	0.45
	3	0.27(0.12–0.63)	0.002	0.34(0.15–0.77)	0.01	0.56(0.19–1.67)	0.30
	≥ 4	0.19(0.08–0.45)	< 0.001	0.25(0.11–0.59)	< 0.001	0.28(0.09–0.90)	0.03

Model 1: unadjusted

Model 2: adjusted for age and gender

Model 3: adjusted for Model 2, race, marital status, educational level, PIR, SBP, DBP, TC, TG, HDL-C, and LDL-C

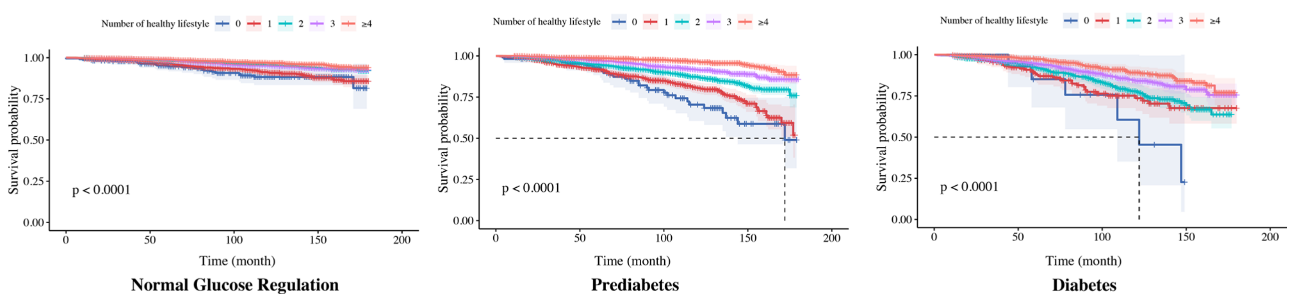

Fig. 2 Kaplan-Meier survival curves between the number of healthy lifestyle and all-cause mortality among participants with normal glucose regulation, prediabetes, and diabetes

increasing adherence to a greater number of healthy lifestyles, according to Fig. 2.

All-cause mortality in relation to PIR among participants with normal glucose regulation, prediabetes, and diabetes

As shown in Table 3, after adjusted multivariate among participants with normal glucose regulation, compared to those with low PIR, those with high PIR have a 53% reduction in the risk of all-cause mortality (HR, 0.47; 95% CI, 0.26–0.83). Among participants with prediabetes and diabetes, all-cause mortality was reduced by 37-65% in those with middle PIR (prediabetes: HR, 0.52; 95% CI, 0.34–0.79, diabetes: HR,0.63; 95% CI, 0.47–0.83) and high PIR (prediabetes: HR, 0.35; 95% CI, 0.18–0.68), diabetes: HR,0.36; 95% CI, 0.24–0.53). Kaplan-Meier curves showed improved survival with increasing adherence to PIR, according to Fig. 3.

Mediation analysis of PIR on associations of healthy lifestyle with all-cause mortality

Table 4 shows the mediating role of PIR in a healthy lifestyle with all-cause mortality. Among people with normal glucose regulation, PIR significantly mediated the association between greater than or equal to two healthy lifestyles and all-cause mortality, of which the number of 2, 3, ≥4 lifestyles explained 9.10%, 7.68% and 5.81% of the association, respectively. Among people with prediabetes, PIR significantly mediated the association between greater than or equal to two healthy lifestyles and all-cause mortality, of which the number of 2, 3, ≥4 lifestyles explained 11.17%, 8.43%, and 7.72% of the association, respectively. However, in diabetic patients, the mediating effect of PIR was not significant.

Secondary analysis and sensitivity analysis

Consistent results were observed when analyses were stratified by age, gender, blood lipid, and blood pressure.

Table 3 Hazard ratio (95% CI) of all-cause mortality according to PIR among participants with normal glucose regulation, prediabetes or diabetes

Glucose metabolic states	PIR	Model 1		Model 2		Model 3	
		HR(95CI%)	*P*	HR(95CI%)	*P*	HR(95CI%)	*P*
Normal Glucose Regulation	Low household income	ref		ref		ref	
	Middle household income	1.07(0.86–1.33)	0.539	0.62(0.49–0.77)	< 0.001	0.74(0.47–1.16)	0.192
	High household income	0.51(0.38–0.68)	< 0.001	0.33(0.25–0.44)	< 0.001	0.47(0.26–0.83)	0.010
Prediabetes	Low household income	ref		ref		ref	
	Middle household income	0.85(0.64–1.13)	< 0.270	0.75(0.57–0.99)	0.044	0.52(0.34–0.79)	0.003
	High household income	0.57(0.39–0.85)	0.005	0.50(0.34–0.74)	< 0.001	0.35(0.18–0.68)	0.002
Diabetes	Low household income	ref		ref		ref	
	Middle household income	1.00(0.82–1.23)	0.975	0.68(0.56–0.84)	< 0.001	0.63(0.47–0.83)	0.001
	High household income	0.47(0.36–0.61)	< 0.001	0.37(0.28–0.49)	< 0.001	0.36(0.24–0.53)	< 0.001

Model 1: unadjusted

Model 2: adjusted for age and gender

Model 3: adjusted for Model 2, race, marital status, educational level, SBP, DBP, TC, TG, HDL-C, and LDL-C

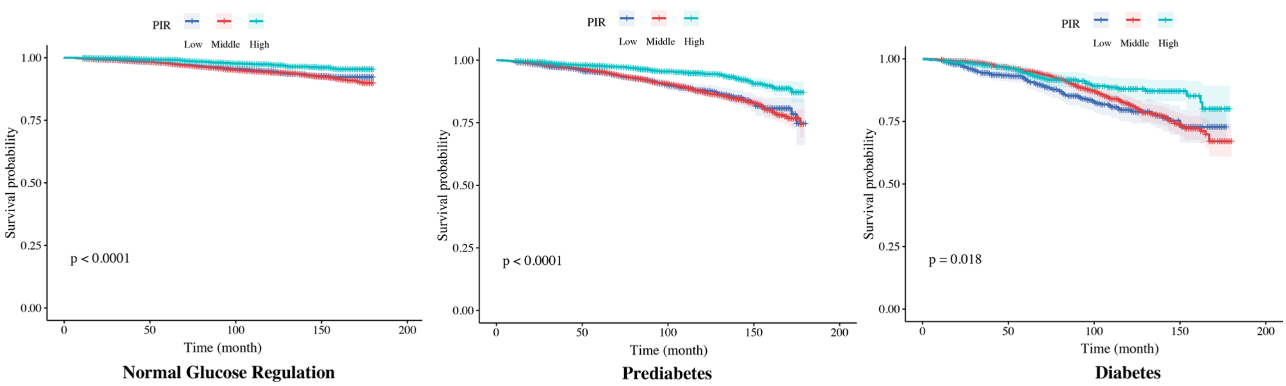

Fig. 3 Kaplan-Meier survival curves between PIR and all-cause mortality among participants with normal glucose regulation, prediabetes, and diabetes

Table 4 Mediation proportion of PIR in all-cause mortality attributed to lifestyle among participants with normal glucose regulation, prediabetes or diabetes

Glucose metabolic states	Number of healthy lifestyle	Mediation effect	Direct effect	Prop. M(%)
		bMed (95% CI)	bDir (95% CI)	
Normal Glucose Regulation	0	ref	ref	
	1	-0.0397 (-0.1136, 0.0043)	-0.2280 (-1.1809, 0.7249)	14.83
	2	-0.0557 (-0.1374, -0.0017)	-0.5564 (-1.4507, 0.3378)	9.10
	3	-0.0597 (-0.1442, -0.0020)	-0.7173 (-1.6097, 0.1751)	7.68
	≥ 4	-0.0715 (-0.1650, -0.0039)	-1.1585 (-2.1140, -0.2030)	5.81
Prediabetes	0	ref	ref	
	1	-0.0636 (-0.1478, 0.0053)	-0.5664 (-1.2604, 0.1276)	10.10
	2	-0.1025 (-0.1971, -0.0296)	-0.8152 (-1.4908, -0.1396)	11.17
	3	-0.1051 (-0.1998, -0.0325)	-1.1418 (-1.8266, -0.4570)	8.43
	≥ 4	-0.1365 (-0.2408, -0.0541)	-1.6317 (-2.4258, -0.8376)	7.72
Diabetes	0	ref	ref	
	1	0.0335 (-0.1425, 0.2753)	-0.5078 (-2.0900, 1.0743)	-7.06
	2	-0.0052 (-0.2013, 0.2046)	-0.6268 (-2.1351, 0.8815)	0.82
	3	-0.0334 (-0.2488, 0.1628)	-0.8679 (-2.3833, 0.6474)	3.71
	≥ 4	-0.0139 (-0.2142, 0.1900)	-1.6529 (-3.2304, -0.0754)	-2.06

Adjusted for sex, gender, race, marital status, educational level, SBP, DBP, TC, TG, HDL-C, and LDL-C. bMed (bmedation), bDir (bdirect), CI: Confidence Interval, Prop. M: Proportion of the Mediating Effect

A healthy lifestyle was associated with at least a 73% reduction in the risk of all-cause mortality in both males and females with prediabetes, while no significant association was observed in males with diabetes (Supplemental Table 2). Only in older people with prediabetes and diabetes, a healthy lifestyle was significantly associated with a 76% and 82% lower risk of all-cause mortality, respectively (Supplemental Table 3). In prediabetes patients with hyperlipidemia and hypertension, a healthy lifestyle was significantly associated with a reduction in the risk of all-cause mortality of at least 79% and 75%, respectively, whereas no significant associations were observed in diabetes patients with hyperlipidemia or hypertension (Supplemental Tables 4 and 5). Consistent with previous results, a healthy lifestyle was more associated with reduced all-cause mortality in each subgroup of prediabetes.

Discussion

To the best of our knowledge, this study aimed to comprehensively investigate the relationship between healthy lifestyle, PIR and all-cause mortality in patients with normal glucose regulation, prediabetes, and diabetes, and further exploring the mediating role of PIR in lifestyle and all-cause mortality risk. A review showed that although many studies have examined lifestyle and all-cause mortality [15], few have compared risks across different glucose metabolism states. In this US national cohort study of 21,411 adults, who had≥2 healthy lifestyle behaviors were associated with 42–76% reduced risk for all-cause mortality among participants with prediabetes, but among those with diabetes, who had≥4 healthy lifestyle behaviors were associated with 72% reduced risk for all-cause mortality.

Participants with lower income had a higher probability of all-cause mortality, with middle-income and high-income groups showing lower multivariate-adjusted HRs compared to the low-income group [26]. A lower risk of all-cause mortality was linked to higher family income and healthier lifestyles. Furthermore, lifestyle factors mediated a small proportion of the association between family income and mortality among US adults. Besides promoting a healthy lifestyle, we should stress how family income inequality affects health outcomes [27]. A population-based cohort study showed that children and adolescents from very-low-income to middle-income families had a higher hazard of youth-onset type 2 diabetes and mortality than those from high-income families [28]. And that individuals who experienced sustained low-income status or an income decrease had elevated T2D risk, while those who had sustained high-income status or an income increase had lowered T2D risk [29]. Therefore, it is important to consider the role of PIR in people with abnormal blood glucose and lifestyle. Considering the effect of PIR, middle and high PIR were associated with at least 37–65% lower risk of all-cause mortality in the participants with normal glucose regulation, prediabetes, and diabetes. In addition, PIR mediated 5.81–14.93% and 7.72–10.10% of the association between a healthy lifestyle and all-cause mortality risk among normoglycemic and prediabetic participants, respectively. However, the mediating effect of PIR was significant among diabetic participants.

Undoubtedly, a healthy lifestyle is one of the important preventive measures to reduce the risk of disease and death. And the association between healthy lifestyle and mortality has been studied in various populations. Studies showed that a healthy lifestyle could reduce the burden of disease and prolong the life expectancy of 900,000 Chinese [30]. In two UK cohorts, the findings suggest that adherence to a healthy lifestyle is associated with longer life expectancy and the absence of major chronic diseases [31, 32]. The 2015–2020 Dietary Guidelines for Americans [33] have emphasized the importance of integrated dietary patterns rather than individual nutritional elements. In this study, we adopted the widely used HEI-2015 to reflect the intake of various nutritional elements comprehensively. Studies have shown that a proper diet can regulate metabolism in various ways, have anti-inflammatory effects, and significantly reduce the incidence of metabolic syndrome. Therefore, a healthy lifestyle should be advocated in patients with prediabetes and diabetes [34]. A low-risk lifestyle has also been found to be protective in patients with type 2 diabetes [17]. In addition, adherence to a healthy lifestyle can improve the life expectancy of patients with comorbidities [31]. This comprehensive review and compilation of data on lifestyle characteristics among people with diabetes demonstrate that healthy lifestyle behaviors are not at optimal rates in the population with diabetes in America [35]. The diabetic population may not be able to engage in more lifestyle practices due to the large disease burden, which may be the reason why this association was not significant in the diabetic population in our study. A review showed that prediabetes is associated with an increased risk of diabetes, cardiovascular events, and mortality [36]. The first-line therapy for prediabetes is lifestyle modification that includes weight loss and exercise or metformin. Lifestyle modification is associated with a larger benefit than metformin. Given the increasing prevalence of prediabetes and diabetes globally, our findings highlight the importance of early interventions targeting healthy lifestyle behaviors and metabolic characteristics of people with prediabetes and diabetes to prevent mortality risk. More emphasis has been placed on multiple healthy lifestyle interventions in prediabetes.

Socioeconomic inequalities in mortality have been widely discussed. Income is one of the leading social determinants of health. A study highlighted the higher prevalence of CVD risk factors, CVD, and mortality in low-income families [8]. In recent studies, income disparity was examined as a component of the social status of NHANES participants [15]. A composite of social risks (PIR, ethnic minority, single life, occupation or employment status, education level, and health insurance) was used in various combinations to quantify social status. Low socioeconomic status was found to be associated with more than two times the risk of all-cause and CVD-related mortality. In addition, socioeconomic inequalities in mortality continue to expand in the US. Low income was associated with a 16% increase in CVD risk and a 19% increase in death risk during follow-up [38]. This current study examined the relationship between PIR and all-cause mortality in participants with different glucose metabolism, which could provide a more precise basis for public health policymaking. Our analyses confirm the PIR in mortality and the effect of middle- and high-household income on the reduction of mortality risk. The results of current study further explored the mediating role of PIR in both normal and prediabetic subjects. The mediation effect of PIR was significant in normal glucose regulation and prediabetic patients but not in diabetic patients, which may be due to the dependence of diabetes treatment on self-management and medication [39]. In a cross-sectional study from 1999 to March 2020, U.S. adults showed varying patterns of change in five healthy lifestyle factors, as well as modest overall lifestyle improvements [40]. But healthcare alone is not sufficient to improve overall health, and changes in the PIR, physical, and policy environment are still needed to improve lifestyles. In addition, the severity of diabetes can influence the impact of healthy lifestyle. Because a healthy lifestyle requires long-term adherence, its effects may become apparent with longer follow-ups. Therefore, there is an urgent need to explore possible ways to reduce family income inequality in the health field and encourage the public to commit to increasing family income to promote healthy lifestyles and reduce the risk of death before glucose metabolism diseases occur.

This study has several important implications. In the nursing of patients with abnormal glucose metabolism, we should emphasize the combination of a variety of healthy lifestyles, especially with early intervention in prediabetes. Additionally, our findings highlight that increasing household income is strongly associated with a reduced risk of all-cause mortality. Clinicians, health systems, payers, policymakers, and other relevant stakeholders should develop targeted interventions to integrate social determinants of health into clinical care to help clinicians deliver targeted care to marginalized populations. Basic strategies include improving access to healthcare, promoting health education, improving housing and food quality, alleviating poverty, and other broad public health and policy.

Strengths and limitation

A major strength of this study includes a wealth of resource information and a long and reliable follow-up, which allowed a comprehensive analysis of mortality. NHANES provides detailed and repeated measures of relevant lifestyle factors, which makes our results sufficiently robust. Our results were further improved and confirmed after adjustment for socioeconomic factors and biochemical measures using generalized linear regression models adjusted for multivariate covariates. Furthermore, analyzing different subgroups makes our results more comprehensive and robust. Based on a large population and a long follow-up period, the current study helps people with different metabolic levels make the right choice. However, our findings focus on income disparities measured using the well-validated PIR, which does not reflect the overall impact of socioeconomic factors on all-cause mortality. Additionally, the target population of NHANES is civilian non-institutionalized residents of the US. Therefore, our findings may not be generalizable to other populations and require further study. The weighted healthy lifestyle score was constructed based on smoking, alcohol consumption, physical activity, diet (HEI-2015), and BMI. The family income to poverty ratio can influence lifestyle, diet, and mortality; however, education and availability of consumer durables, such as a refrigerator for storing vegetables, a car for transport, or availability of gym in the house, can also influence lifestyle and mortality. The effect of these factors could not be fully accounted for in this study.

Conclusion

In this US national cohort study of 21,411 adults, who had ≥ 2 healthy lifestyle behaviors were associated with 42–76% reduced risk for all-cause mortality among participants with prediabetes, but among those with diabetes, who had ≥ 4 healthy lifestyle behaviors were associated with 72% reduced risk for all-cause mortality. Considering the effect of PIR, moderate and high PIR were associated with at least a 37–65% lower risk of all-cause mortality in the population with and without prediabetes. In addition, PIR mediated 5.81-14.93% and 7.72 -10.10% of the association between healthy lifestyle and risk of all-cause mortality among normoglycemic and prediabetic participants, respectively. However, the mediating effect of PIR was significant among diabetic participants. Our findings highlight the importance of promoting healthy lifestyle adherence in prediabetes and improving PIR for pre-risk of all-cause mortality.

Abbreviations

PIR	Income to poverty ratio
NHANES	National Health and Nutrition Examination Survey
HEI	Healthy eating index
SBP	Systolic blood pressure
DBP	Diastolic blood pressure
FPG	Fasting plasma glucose
TC	Total cholesterol
HDL-C	High-density lipoprotein cholesterol
TG	Triglycerides
LDL-C	Low-density lipoprotein cholesterol
HbA1c	Glycated haemoglobin
HR	Hazard ratios
CI	Confidence intervals
IQR	Interquartile range

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-024-21206-0.

Supplementary Material 1: Table 1. HEI–2015 components and scoring standards. Table 2. Hazard Ratio (95% CI) of healthy lifestyle and all-cause mortality among participants with normal glucose regulation, prediabetes or diabetes according to gender. Table 3. Hazard Ratio (95% CI) of healthy lifestyle and all-cause mortality among participants with normal glucose regulation, prediabetes or diabetes according to age. Table 4. Hazard Ratio (95% CI) of healthy lifestyle and all-cause mortality among participants with normal glucose regulation, prediabetes or diabetes according to blood lipid. Table 5. Hazard Ratio (95% CI) of healthy lifestyle and all-cause mortality among participants with normal glucose regulation, prediabetes or diabetes according to blood pressure.

Author contributions

XF and ZL participated in the study design, statistical analysis, analyzed the data together and drafted the manuscript; LZ, YSW, TD, and YXG participated in data verification. All authors have read and approved the final manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

NHANES was approved by NCHS Ethics Review Board (https://www.cdc.gov/nchs/nhanes/irba98.htm). The patients/participants provided their written informed consent to participate in this study. Ethical approval was not provided for this study on human participants because the data were all accessed from NHANES. This study was performed in accordance with the Declaration of Helsinki.

Competing interests

The authors declare no competing interests.

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