BMC Public Health

RESEARCH

Open Access

Association between oxidative balance scores and all-cause and cardiovascular disease-related mortality in patients with type 2 diabetes: data from the national health and nutrition examination survey (2007–2018)

Hao Wang[1†], Yan-Lin Chen[2†], Xiang-Ming Li[3], Qi Wu[4], Yan Xu[1*] and Jin-Song Xu[1*]

Abstract

Background Oxidative Balance Scores (OBS) is composite measures that assess the balance between pro-oxidant and antioxidant factors in an individual's diet and lifestyle. Evidence on OBS and cardiovascular disease (CVD) in diabetic patients is scarce. This study investigates the potential association between OBS and CVD-prevalence and all-cause and CVD-related mortality in adult diabetic patients.

Methods Participants were selected from the National Health and Nutrition Examination Survey (NHANES) 2007–2018. OBS-related data collection was initiated by linking the National Death Index to determine mortality due to all-cause and cardiovascular disease until December 31, 2019. Weighted logistic regression analyses explored the relationship between OBS and CVD. In addition, multivariable Cox proportional risk regression models and Kaplan–Meier curves were used to determine the correlation between OBS and mortality, with time to event as the time variable, as well as to estimate hazard ratios (HR) and 95% confidence interval (CI).

Results A total of 3491 participants were included in the final analysis. Weighted logistic regression analysis of the relationship between OBS and CVD prevalence found that higher OBS was not associated with CVD prevalence compared with lower levels after fully adjustment in model 3 (OR: 0.82, 95% CI: 0.51–1.31, $P=0.39$). During 3,491 person-years of follow-up, 408 deaths were recorded, of which 105 deaths were attributed to CVD. In fully adjusted model 3, participants in the highest quartile of OBS had significant reductions in all-cause mortality of 53% [HR: 0.47, 95% CI: 0.29–0.77), $P_{trend}= 0.002$] and in cardiovascular disease mortality of 78% [HR: 0.22, 95% CI: 0.08–0.56), $P_{trend}= 0.004$], compared with the lowest quartile groups of OBS. The Kaplan–Meier analysis results showed that participants in the highest quartile of OBS had the lowest risk of all-cause and CVD-related mortality and were statistically different

†Hao Wang and Yan-Lin Chen contributed equally to this work.

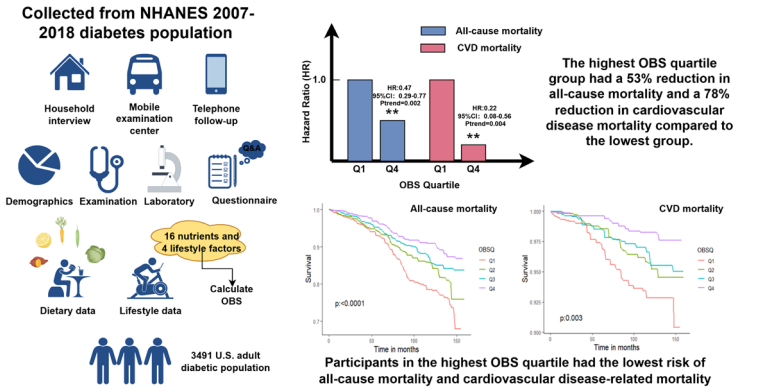
*Correspondence:
Yan Xu
xiao86xu@163.com
Jin-Song Xu
xujingsong0505@163.com; ndefy03015@ncu.edu.cn

Full list of author information is available at the end of the article

(*P* < 0.05). Subgroup analysis confirmed that P for interaction was significant only concerning the educational level attained and in individuals with a history of CKD (*P* < 0.05).

Conclusions Although OBS wasn't very useful for assessing CVD prevalence outcomes, higher OBS was significantly associated with lower all-cause and CVD-related mortality, suggesting that maintaining adequate OBS may reduce mortality in patients with DM.

Graphical Abstract



Association between OBS and mortality in adults with Type 2 Diabetes from NHANES (2007–2018)

Keywords Oxidative balance score, Diabetes, Mortality, Cardiovascular disease, NHANES

Introduction

In recent decades, the global prevalence of diabetes mellitus (DM), a complex, chronic metabolic disease, has been steadily increasing [1]. The number of adults with DM is estimated to increase to 693 million by 2045 [2], making it a global public health concern. Individuals with DM have a two- to four-fold higher risk of cardiovascular disease (CVD) and death than those without DM [3]. Moreover, CVD remains the leading cause of death in patients with type 2 DM (T2DM); therefore, to delay the onset of complications related to DM, underappreciated risk factors must be identified early in patients with T2DM and strategies for prompt intervention should be developed urgently to reduce the risk of CVD in patients with DM [4].

An imbalance between oxidant production and antioxidant activity in cells and plasma generates oxidative stress, which is the underlying mechanism involved in the development of T2DM and its complications [5]. Oxidant overproduction results from mitochondrial dysfunction and overactivation of NADPH oxidase [6]. In the diabetic state, increased oxidative stress may accelerate the onset of complications through excess glucose and free fatty acid metabolism [7], necessitating early recognition and prompt intervention. However, various dietary components, tobacco use, alcohol consumption, and physical activity all influence the level of oxidative stress in vivo, so it is reasonable to consider multiple factors in assessing the impact of the entire oxidative/antioxidant system. Oxidative Balance Score (OBS), developed as a comprehensive diet and lifestyle assessment tool, estimates the overall oxidative stress exposure to capture the effects of various dietary patterns and lifestyles on the entire oxidative/antioxidant system [8].

The OBS is calculated using 16 nutrients and four lifestyle factors, including five pro-oxidant and 15 antioxidant exposures [9]. Data related to the dietary intakes of 16 nutrients, including dietary fiber, carotene, riboflavin, niacin, vitamin B6, total folate, vitamin B12, vitamin C, vitamin E, calcium, magnesium, zinc, copper, selenium, total fat, and iron, are obtained from the first dietary review interview. The main lifestyle factors comprise physical activity, alcohol consumption, body mass index (BMI), and smoking, which is measured as the degree of tobacco use expressed in terms of cotinine. Of these, total fat, iron, BMI, alcohol consumption, and smoking are considered pro-oxidants, and the rest are antioxidants [8]. Based on the above compositional calculations, a higher OBS value indicates that there are more antioxidants present than pro-oxidants. This suggests that the substance with the higher OBS value is better at neutralizing harmful free radicals and protecting against oxidative stress. Furthermore, people with high OBS are less likely to develop DM [10, 11]. At the same time, Iranian adults with type-2 diabetes with higher OBS have better glycemic control [12], suggesting a close relationship between OBS and the development of DM. A large prospective cohort showed that higher OBS was associated

with a lower risk of all-cause mortality and mortality from cancer and non-cancer causes [13]. However, the potential relationship between OBS and CVD-prevalence and all-cause and CVD-related mortality in patients with DM remains to be elucidated.

Herein, we examined the association between OBS and CVD-prevalence and all-cause and CVD-related mortality in patients with T2DM who participated in the National Health and Nutrition Examination Survey (NHANES) between 2007 and 2018.

Methods

Study population

The NHANES is a nationally representative survey of the United States. A project of the National Center for Health Statistics (NCHS) Study, approved and sponsored by the Centers for Disease Control and Prevention, NHANES is designed to assess the health and nutritional status of noninstitutionalized US civilians. This survey uses a complex multistage probability sampling procedure to collect data every 2-year cycle, and the five major components include demographic, dietary, examination, laboratory, and questionnaire data. NHANES was reviewed and approved by the NCHS Research Ethics Review Board, and informed consent was obtained from all participants. The NHANES data are publicly available, and for more information about how the survey data are collected and analyzed, see https://www.cdc.gov/nchs/nhanes.

To conduct this study, we included adults with DM aged between 20 and 80 years who had completed an OBS assessment and for whom follow-up data from six consecutive cycles of NHANES from 2007 to 2018 were available. Details of the sampling and exclusion criteria for the current study are shown in Fig. 1. A total of 59,842 participants were initially enrolled, of whom 28,676 were aged < 20 years or > 80 years. After excluding participants with missing OBS components (n = 13,939), missing data on covariates (n = 314), missing data on CVD (n = 2), and the nondiabetic population (n = 13,420), the final sample consisted of 3,491 adults (Fig. 1).

Calculation of OBSs

Briefly, the overall OBS was calculated by combining the individual scores of each variable, i.e., 16 dietary and four lifestyle components of OBS [8], with higher OBS scores indicating more significant antioxidant exposure. We used the cotinine test that is used to estimate smoking to measure tobacco use and exposure to environmental tobacco smoke. In addition, the participants were categorized based on the level of alcohol consumption as nondrinkers, nonheavy drinkers (0–15 g/d for women and 0–30 g/d for men), and heavy drinkers (≥15 g/d for women and ≥30 g/d for men) with scores of 2, 1, and 0, respectively [8]. Based on gender, the other components were grouped in thirds. The antioxidant group was assigned scores of 0, 1, and 2 from tertile 1 to tertile 3, respectively, whereas in the pro-oxidant group, tertile 3 was assigned a score of 0, and tertile 1 was assigned a score of 2 [8, 14]. Furthermore, based on OBS quartiles, the lowest quartile was used in the weighted logistic regression model for comparison.

Evaluation of DM

There were six diagnostic criteria for DM: previous diagnosis of DM by a physician, fasting glucose ≥ 7.0 mmol/L, random blood glucose ≥ 11.1 mmol/L, 2-h oral glucose tolerance test ≥ 11.1 mmol/L, glycated hemoglobin (HbA1c) > 6.5%, and use of DM medication or insulin [11].

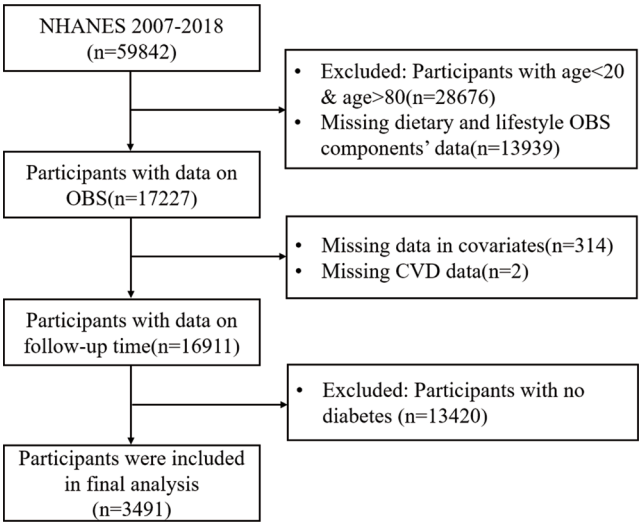


Fig. 1 Flow chart of study participants

Covariates

We selected covariates that may be potential confounders in the association between OBS and DM based on existing literature and clinical considerations. Data were collected through household interviews performed using a standardized questionnaire on age, sex, race, education level, marital status, poverty-to-income ratio, dietary energy intake, smoking status, physical activity, disease status, and substance use.

We categorized race as non-Hispanic white, non-Hispanic black, Mexican American, and others. Educational attainment was categorized as <12 years or ≥12 years based on the number of academic years. Marital status was categorized as divorced, separated, widowed, married, living with a partner, and never married. The poverty-to-income ratio, which is the total household income divided by the poverty threshold, is an indicator of poverty status. It is categorized into three categories according to the analysis guide: ≤1.3, 1.3–3.5, and >3.5[(15)]. There were three categories of smoking status: never smoked, former smoker, and current smoker. Aerobic physical activity was classified into three categories based on the US Physical Activity Guidelines 2018 [16]: low (<150 min/week), moderate (150–300 min/week), and high (>300 min/week). The use of insulin or oral hypoglycemic agents indicated drug use. In addition, serum cholesterol (mmol/L), triglycerides (mmol/L), and glycated hemoglobin were measured at baseline when participants provided blood samples. By dividing body weight by height squared, BMI was calculated and categorized as normal weight (<25 kg/m^2), overweight (25–30 kg/m^2), and obese (>30 kg/m^2). Comorbidities included hypertension, hyperlipidemia, and chronic kidney disease (CKD). Hypertension was defined as a systolic blood pressure≥140 mmHg or diastolic blood pressure≥90 mmHg after at least three measurements, use of antihypertensive medications, and a diagnosis of hypertension reported by the patient or physician [17]. Hyperlipidemia was defined as total cholesterol≥200 mg/dL (mg/dL), triglycerides≥150 mg/dL, LDL≥130 mg/dL, and HDL<40 mg/dL [18]. Alternatively, participants reporting the use of lipid-lowering medications were classified as having hyperlipidemia. CKD was identified by a urinary albumin-to-creatinine ratio≥30 mg/g and/or eGFR<60 mL/min/1.73 m^2 [19].

Outcome variable selections

The outcomes selected in this study were CVD-prevalence and all-cause and CVD-related mortality. A combination of self-reported physician diagnosis and standardized health status or medical history questionnaires from personal interviews was used to determine whether a patient had CVD [20]. The participants were asked, "Has a doctor or other health professional ever told you that you have had a heart attack/coronary heart disease/angina/congestive heart failure/stroke?" A person was regarded as having CVD if they replied "yes" to any of the above questions. OBS-related data collection was initiated by linking the National Death Index to determine mortality due to all-cause and cardiovascular disease until December 31, 2019. The International Classification of Diseases (ICD)-10 (codes I00–I09, I11, I13, I20–I51, or I60–I69) were used to determine CVD-related mortality. The NCHS website provides the "2019 Public Use-Related Mortality File" (https://www.cdc.gov/nchs/data-linkage/mortality-public.htm). Furthermore, participants without a matching death record throughout the follow-up period were considered alive.

Statistical analysis

All statistical analyses were performed with R software (version 4.3.2) and conducted according to the NHANES analysis guidelines, owing to the complexity of the NHANES sampling design [15]. To calculate the 12-year sampling weights using one-sixth of the 2-year sampling weights (WTMEC2YR), we combined data from six continuous cycles of the survey. Study participants were categorized into four groups based on quartiles (Q1–Q4) of OBS, Q1 (OBS, 4–14), Q2 (OBS, 14–20), Q3 (OBS, 20–26), and Q4 (OBS, 26–36). Weighted means and standard errors were presented for continuous variables, and frequency plus weighted percentages were presented for categorical variables. Baseline characteristics of OBS quartile groups were compared using a one-way analysis of variance for continuous variables and Pearson chi-square tests for categorical variables. Weighted logistic regression analyses explored the relationship between overall OBS, dietary OBS, lifestyle OBS, and CVD. Three analytic models were developed to eliminate the effects of covariates: model 1 was unadjusted; model 2 was adjusted for age, race, and sex; and model 3 was adjusted for age, sex, race, education, marital status, poverty, total energy intake, smoking status, total cholesterol, triglycerides, HbA1c, BMI, history of hypertension, hyperlipidemia, or CKD, and hypoglycemic drug use. In addition, restricted cubic spline and smoothed curve fitting (penalized spline method) were used to assess the nonlinear relationship between OBS and CVD. In addition, multivariable Cox proportional risk regression models and Kaplan–Meier curves were used to determine the correlation between OBS and mortality, with time to event as the time variable, as well as to estimate hazard ratios (HRs) and 95% confidence interval (CI). Stratified analyses were used to evaluate the differences in the baseline characteristics of the selected participants. We stratified data based on sex, age (<60 or ≥60 years), BMI (<25.00 or ≥25.00), race (white, black, Mexican, or other), education (<12 or ≥12), poverty level (low, middle, or high), HbA1c (<7 or

≥7), hyperglycemic drug use, history of hypertension, hyperlipidemia, or CKD, and CVD subtypes (angina, stroke, heart attack, coronary heart disease, and congestive heart failure). All statistical tests were two-sided, and statistical significance was set at $P<0.05$.

Results

Baseline characteristics of study participants

Table 1 shows the baseline characteristics of study participants ($n=3491$) based on OBS quartiles. The 3,491 NHANES participants (mean age, 56.12 years; male: 56.86%) with valid OBSs represent approximately 21.49 million noninstitutionalized US residents. Individuals with higher OBS levels were more likely to be married, less likely to be non-Hispanic black, and less likely to be obese or currently smoking than those in the lowest quartile. They also reported higher levels of education, household income, total energy intake, and physical activity.

Relationship between OBS and the risk of CVD

Table 2 shows the logistic regression-based correlation between OBS and the risk of CVD. We found that participants in the highest quartile of OBS and dietary OBS in unadjusted model 1 had lower CVD risk (odds ratio [OR]: 0.60, 95% CI: 0.44–0.82, $P<0.002$; OR: 0.63, 95% CI: 0.48–0.82, $P<0.001$). In model 2, partially adjusted for potential confounding variables, the association was found to remain significant; the risk of CVD was lower in the highest quartile of OBS, dietary OBS, and lifestyle OBS when compared to the lowest quartile of OBS (OR: 0.59, 95% CI: 0.41–0.84, $P=0.004$; OR: 0.67, 95% CI: 0.49–0.92, $P=0.01$; OR:0.44, 95% CI:0.30–0.64, $P<0.001$). However, after full adjustment in model 3, none of the highest quartiles of OBS, dietary OBS, and lifestyle OBS were associated with risk of CVD compared with the lowest quartile of OBS (OR: 0.82, 95% CI: 0.51–1.31, $P=0.39$; OR: 0.80, 95% CI: 0.52–1.23, $P=0.31$; OR: 0.99, 95% CI: 0.54–1.79, $P=0.96$). Moreover, no statistically significant difference was observed in p for trend (P_{trend}) for any of the three OBSs ($P=0.424$; $P=0.335$; $P=0.671$).

Restricted cubic splines showed a negative linear trend in the association between the risk of CVD and OBS, dietary OBS, and lifestyle OBS (P for nonlinearity=0.134; P for nonlinearity=0.176; P for nonlinearity=0.799; Fig. 2).

OBS and mortality risk

During the 22,316 person-years of follow-up in NHANES 2007–2018 (median follow-up time of 6.11 years), 408 deaths were recorded, of which 105 deaths were attributed to CVD. We constructed three Cox regression models to investigate independent correlations between the mortality risk and OBS, dietary OBS, and lifestyle OBS, respectively.

As shown in Table 3 in unadjusted model 1, participants in the highest quartile groups of total OBS and dietary OBS had a significant reduction in risk of all-cause mortality by 57% and 60%, respectively, and in risk of CVD-related mortality by 75% and 67%, respectively when compared to the lowest quartile groups of total OBS and dietary OBS, with all $P_{trend}<0.0001$; however, this was not observed in the lifestyle OBS. In partially adjusted model 2, all-cause and CVD-related mortality decreased significantly with increasing total OBS and dietary OBS; however, in the highest quartile of the population with lifestyle OBS, all-cause mortality (HR [95% CI]: 0.65 [0.47,0.91]), $P_{trend}=0.003$, CVD-related mortality (HR [95% CI]: 0.67 [0.36,1.24]), $P_{trend}=0.203$. In fully adjusted model 3, participants in the highest quartile of total OBS and dietary OBS had significant reductions in all-cause mortality of 53% [HR: 0.47, 95% CI: 0.29–0.77), $P_{trend}= 0.002$] and 48% [HR: 0.52, 95% CI: 0.32–0.84), $P_{trend}= 0.013$] and in cardiovascular disease mortality of 78% [HR: 0.22, 95% CI: 0.08–0.56), $P_{trend}= 0.004$] and 62% [HR: 0.38, 95% CI: 0.15–0.96), $P_{trend}= 0.047$], respectively, compared with the lowest quartile groups of total OBS and dietary OBS, with statistically significant differences in P_{trend}; however, in the highest quartile of the population with lifestyle OBS all-cause mortality HR (95% CI): 0.51 (0.29,0.89), $P_{trend}=0.012$, CVD mortality HR (95% CI): 0.49 (0.21,1.13), $P_{trend}=0.066$.

The Kaplan–Meier analysis results showed that participants in the highest quartile of OBS and dietary OBS had the lowest risk of all-cause and CVD-related mortality and were statistically different (shown in Fig. 3), which was not observed in lifestyle OBS.

Stratified analyses

Data were stratified according to age, gender, race, education, poverty level, HbA1c, hyperglycemic drug use, hypertension, hyperlipidemia, CKD, and CVD into subgroups, as shown in Table 4. Our results showed that OBS was negatively associated with all-cause mortality in group Q4, especially among participants aged≥60 years, men, non-Hispanic whites, individuals with low-to-middle income, those with HbA1c≥7, those who used medications for DM, and those with a history of hypertension, hyperlipidemia, or CKD. In addition, OBS was negatively associated with CVD mortality in the Q4 group, especially among participants aged≥60 years, women, non-Hispanic whites, middle-income individuals, those with HbA1c≥7, those who used medications for DM, those with a history of hypertension or hyperlipidemia, and those who had no previous strokes, cardiac events, or coronary heart disease. P for interaction was significant

Table 1 The baseline characteristics by quartiles of the OBS: NHANES 2007–2018

Characteristic	Total *n* = 3491	Q1 [4, 14] *n* = 882	Q2 [14, 20] *n* = 932	Q3 [20, 26] *n* = 970	Q4 [26, 36] *n* = 707	*P* value
Age (years)	56.12(0.34)	56.29(0.79)	55.97(0.57)	55.67(0.54)	56.75(0.59)	0.54
Sex, n (%)						0.88
Female	1504(43.14)	355(20.32)	417(26.77)	430(30.76)	302(22.15)	
Male	1987(56.86)	527(19.93)	515(26.50)	540(29.65)	405(23.91)	
Race, n (%)						< 0.0001
Non-Hispanic White	1417(67.66)	331(18.12)	368(26.67)	417(30.62)	301(24.59)	
Non-Hispanic Black	781(11.32)	269(33.41)	217(27.54)	173(23.49)	122(15.56)	
Mexican American	569(8.58)	120(18.72)	154(26.22)	162(30.76)	133(24.31)	
Other	724(12.44)	162(19.73)	193(25.79)	218(33.03)	151(21.45)	
Education level, n (%)						< 0.0001
< 12	1718(41.86)	539(26.12)	477(28.03)	423(27.35)	279(18.51)	
≥ 12	1773(58.14)	343(15.77)	455(25.61)	547(32.13)	428(26.49)	
Marital status, n (%)						0.004
Divorced	449(12.45)	116(21.05)	135(30.01)	114(28.20)	84(20.74)	
Separated	123(2.11)	31(25.15)	37(27.46)	33(31.30)	22(16.09)	
Widowed	352(8.39)	109(25.30)	90(22.95)	86(28.71)	67(23.03)	
Married	2012(61.56)	450(17.04)	535(27.43)	593(31.41)	434(24.12)	
Living with a partner	184(5.49)	62(31.62)	33(14.54)	53(29.68)	36(24.15)	
Never married	371(10.01)	114(26.00)	102(26.92)	91(25.83)	64(21.25)	
Poverty, n (%)						< 0.0001
< 1.3	1071(19.67)	363(32.76)	298(26.80)	262(26.08)	148(14.35)	
1.3-0.35	1381(37.57)	342(21.59)	381(27.68)	374(28.68)	284(22.05)	
> 3.5	1039(42.76)	177(12.97)	253(25.60)	334(33.26)	275(28.17)	
Total energy intake (kcal)	2074.19(20.17)	1383.55(25.60)	1846.50(29.47)	2260.92(33.57)	2692.70(53.47)	< 0.0001
Smoking status, n (%)						< 0.001
Former	1142(34.89)	300(21.21)	296(25.42)	307(29.14)	239(24.23)	
Never	1768(49.59)	386(17.33)	468(26.69)	509(30.26)	405(25.72)	
Now	579(15.48)	195(26.38)	167(29.07)	154(32.00)	63(12.54)	
TG (mg/dL)	180.64(3.55)	180.39(6.01)	178.95(7.83)	191.42(6.64)	168.75(6.49)	0.08
TC (mg/dL)	188.97(1.25)	188.52(2.39)	191.04(2.13)	188.03(1.92)	188.22(2.23)	0.71
HbA1c (%)	6.60(0.04)	6.69(0.06)	6.64(0.07)	6.56(0.06)	6.51(0.07)	0.16
BMI (kg/m^2)						0.003
< 25	489(12.67)	116(17.68)	106(22.56)	136(26.89)	131(32.87)	
25–30	1069(29.43)	248(17.54)	275(26.24)	301(30.78)	245(25.43)	
≥ 30	1933(57.91)	518(21.93)	551(27.70)	533(30.50)	331(19.86)	
Hypertension, n (%)						0.24
No	1249(38.01)	285(19.25)	334(25.56)	359(29.44)	271(25.75)	
Yes	2242(61.99)	597(20.63)	598(27.27)	611(30.55)	436(21.55)	
Hyperlipidemia, n (%)						0.72
No	498(13.54)	120(19.20)	134(26.55)	124(28.51)	120(25.75)	
Yes	2993(86.46)	762(20.24)	798(26.63)	846(30.38)	587(22.74)	
CKD, n (%)						< 0.001
No	464(11.77)	159(30.18)	120(26.91)	114(27.54)	71(15.37)	
Yes	3027(88.23)	723(18.76)	812(26.58)	856(30.47)	636(24.19)	
Hypoglycemic drugs						0.84
No	685(19.03)	166(19.74)	183(28.04)	190(28.58)	146(23.65)	
Yes	2806(80.97)	716(20.19)	749(26.29)	780(30.49)	561(23.03)	
Physical Activity, n (%)						0.02
Low	830(22.49)	256(24.35)	238(28.93)	214(29.21)	122(17.51)	
Moderate	683(19.54)	171(21.09)	174(27.36)	195(30.12)	143(21.43)	
High	1978(57.97)	455(18.12)	520(25.48)	561(30.49)	442(25.92)	

Table 1 (continued)

Characteristic	Total *n* = 3491	Q1 [4, 14] *n* = 882	Q2 [14, 20] *n* = 932	Q3 [20, 26] *n* = 970	Q4 [26, 36] *n* = 707	*P* value
OBS. dietary	16.69(0.17)	7.40(0.10)	13.68(0.09)	19.37(0.09)	24.75(0.10)	< 0.0001
OBS. lifestyle	4.19(0.04)	3.75(0.06)	4.08(0.06)	4.20(0.06)	4.68(0.06)	< 0.0001

Abbreviations TG, triglycerides; TC, total cholesterol; HbA1c, hemoglobin A1c; BMI, body mass index; Date are presented as mean (SE) or n (%)

Table 2 Weighted logistic regression analysis models showing the associations between OBS and CVD

	Model 1		Model 2		Model 3	
	OR 95%CI	*P* value	OR 95%CI	*P* value	OR 95%CI	*P* value
OBS Quartile						
Q1	Ref		Ref		Ref	
Q2	0.57(0.41,0.78)	< 0.001	0.57(0.40,0.81)	0.002	0.67(0.47,0.95)	0.03
Q3	0.57(0.42,0.77)	< 0.001	0.58(0.42,0.79)	< 0.001	0.67(0.46,0.99)	0.04
Q4	0.60(0.44,0.82)	0.002	0.59(0.41,0.84)	0.004	0.82(0.51,1.31)	0.39
p for trend		0.004		0.009		0.424
OBS. dietary Quartile						
Q1	Ref		Ref		Ref	
Q2	0.67(0.47,0.96)	0.03	0.66(0.45,0.97)	0.03	0.72(0.49,1.04)	0.08
Q3	0.57(0.41,0.79)	< 0.001	0.58(0.41,0.83)	0.003	0.63(0.41,0.97)	0.04
Q4	0.63(0.48,0.82)	< 0.001	0.67(0.49,0.92)	0.01	0.80(0.52,1.23)	0.31
p for trend		0.002		0.024		0.335
OBS. lifestyle Quartile						
Q1	Ref		Ref		Ref	
Q2	0.82(0.58,1.16)	0.27	0.69(0.49,0.99)	0.04	0.91(0.63,1.32)	0.61
Q3	1.04(0.78,1.38)	0.80	0.77(0.57,1.06)	0.10	1.13(0.75,1.70)	0.55
Q4	0.75(0.52,1.07)	0.11	0.44(0.30,0.64)	< 0.0001	0.99(0.54,1.79)	0.96
p for trend		0.452		< 0.001		0.671

Model 1: Unadjusted model

Model 2: Adjusted for age, sex, and race

Model 3: Additionally adjusted for education, marital status, poverty, total energy intake, smoking status, total cholesterol, triglycerides, HbA1c, BMI, history of hypertension, history of hyperlipidemia, history of CKD, and hypoglycemic drugs

The specific range for the quantiles is consistent with Table 1

only concerning the educational level attained and in individuals with a history of CKD.

Discussion

To our knowledge, this is the first study to use OBS to examine the relationship between the oxidative/antioxidant system and CVD prevalence and CVD-related mortality in patients with DM. In the weighted logistic regression fully corrected model, no statistically significant association was observed between OBS and CVD prevalence in patients with DM. However, restricted cubic spline curves showed a negative linear trend in the correlation between the three types of OBS and the CVD risk. Furthermore, high OBSs are associated with reduced risks of developing diabetes [10, 11], stroke [14], nonalcoholic fatty liver disease [21], and gastric cancer [22]. Researchers in South Korea [23] found that individuals with higher OBSs had a lower risk of developing new-onset hypertension, while another study using data from the NHANES 2005 to 2018 in which adult population reported that increased risk of overall and specific CVD was associated with decreased OBSs [24], suggesting that OBS as an oxidative/antioxidant indicator is related to the prevalence of CVDs and that higher OBS is associated with a lower risk of CVD. Moreover, the fact that only diabetic populations were included in our study may explain this discrepancy.

A growing body of evidence supports that higher intakes of dietary fiber [25], riboflavin [26], carotenoids [27], vitamin C [28, 29], and vitamin E [30, 31], as well as regular physical activity [32, 33], may reduce oxidative stress. Conversely, pro-oxidant factors, including iron [34, 35] intake, obesity [36], smoking [37], and alcohol intake [38, 39], increase the production of reactive oxygen species (ROS) and accelerate oxidative stress-induced cellular damage. We know that oxidative stress occurs when the amount of ROS exceeds the neutralizing capacity of antioxidants [40]. Caturano et al. [41] showed that the pathogenesis and progression of diabetes mellitus and its complications are closely associated with oxidative stress and that dietary strategies to combat oxidative stress include increased consumption of

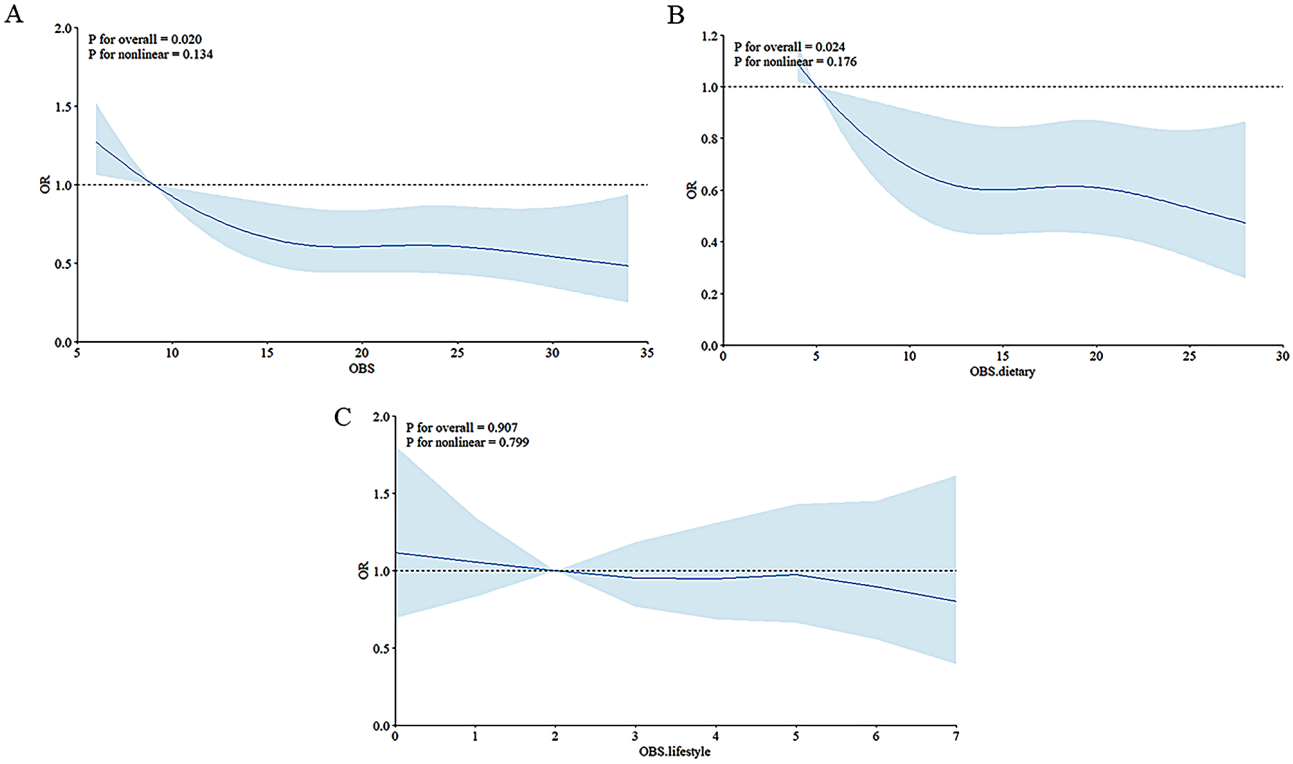


Fig. 2 Correlation between OBS, dietary OBS, and lifestyle OBS, and risk of CVD prevalence. (**A**) OBS; (**B**) Dietary OBS; (**C**) Lifestyle OBS. *Abbreviation* OBS, oxidative balance score; OR, odds ratio

carotenoids, which not only stimulates the immune system but also contributes to ROS elimination by activating the nuclear factor erythroid 2-related factor 2 (NRF2). In addition, lycopene ameliorates T2DM by activating antioxidant systems such as superoxide dismutase and glutathione peroxidase [42], and vitamin E activates NRF2 and heat shock proteins and protects cell membranes from ROS while downregulating nuclear factor-kappa B (NF-κB) [43]. Therefore, in patients with DM, oxidative stress assessment becomes imperative. The relationship between OBS and mortality in diabetic populations has not been examined thus far, with previous studies examining only the relationship between a single OBS component and mortality. The results showed that high dietary intakes, and/or blood levels of vitamin C, carotenoids, and α-tocopherol (markers of fruit and vegetable consumption) were associated with lower cardiovascular disease, and mortality risks [44]. Liu et al. [45] investigated the relationship between serum folate and vitamin B12 concentrations and CVD-related mortality in patients with T2DM. Wang et al. [46] investigated the association between cobalamin intake and related biomarkers and the risk of mortality in patients with T2DM. Still, we know that single-component pro-oxidants or antioxidants may have antagonistic and synergistic interactions in the organism that do not necessarily truly reflect the overall antioxidant profile. As a result, we used OBS in this study to determine overall oxidative/antioxidant balance, which may be a better indicator of oxidative stress status.

DM is one of the crucial independent risk factors for CVD, and patients with DM and pre-diabetes account for almost 65% of all CVD-related deaths [47]. According to a large prospective cohort study, higher OBS may decrease the risk of premature all-cause and cancer-related mortality by balancing anti-oxidant and pro-oxidant lifestyle exposures [13]. To examine the impact of OBSs on all-cause and CVD-related mortality in patients with DM, we analyzed the association between OBSs and both types of mortality. Fully adjusted model 3 showed reduced all-cause and CVD mortality among diabetic patients with higher total and dietary OBS. In the K-M analysis, participants in the highest quartile of OBS and dietary OBS had the lowest all-cause and CVD mortality, suggesting that dietary and lifestyle interventions may reduce the risk of CVD-related mortality by improving the antioxidant capacity of an individual. According to one study, older women with higher lifestyle OBS had lower all-cause, all-CVD, and all-cancer mortality [48]. However, the OBS in their study included 11 dietary components and 4 lifestyle components (physical activity, obesity, alcohol, and smoking). In contrast, we assessed the antioxidant capacity using a more comprehensive tool in our study, which evaluated OBS related to 16

Table 3 HR (95% CI) of all-cause and CVD-related mortality according to quartiles of OBS

Mortality type/ OBS variable forms	No. deaths/total	OBS. Total			OBS. Dietary			OBS. Lifestyle		
		Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
		HR 95%CI	HR 95%CI	HR 95%CI	HR 95%CI	HR 95%CI	HR 95%CI	HR 95%CI	HR 95%CI	HR 95%CI
CVD	105/3491									
Quartile										
Q1	36/882	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Q2	30/932	0.59(0.33,1.05)	0.65(0.35,1.23)	0.64(0.31,1.32)	0.64(0.34,1.20)	0.74(0.38,1.44)	0.81(0.39,1.68)	0.63(0.32,1.23)	0.53(0.27,1.01)	0.50(0.24,1.02)
Q3	26/970	0.54(0.30,0.97)	0.61(0.32,1.14)	0.69(0.32,1.48)	0.51(0.27,0.96)	0.58(0.30,1.13)	0.71(0.30,1.64)	0.90(0.52,1.57)	0.62(0.35,1.09)	0.52(0.28,0.99)
Q4	13/707	0.25(0.13,0.49)	0.25(0.12,0.52)	0.22(0.08,0.56)	0.33(0.19,0.57)	0.37(0.20,0.71)	0.38(0.15,0.96)	1.25(0.69,2.28)	0.67(0.36,1.24)	0.49(0.21,1.13)
P trend		< 0.0001	< 0.001	0.004	< 0.0001	0.001	0.047	0.547	0.203	0.066
All-cause	408/3491									
Quartile										
Q1	137/882	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Q2	109/932	0.75(0.52,1.08)	0.82(0.57,1.18)	0.88(0.60,1.29)	0.70(0.50,0.99)	0.77(0.53,1.13)	0.88(0.59,1.33)	0.66(0.44,1.00)	0.58(0.38,0.87)	0.60(0.40,0.91)
Q3	104/970	0.59(0.45,0.78)	0.65(0.49,0.87)	0.81(0.58,1.14)	0.63(0.46,0.86)	0.70(0.51,0.98)	0.88(0.59,1.31)	0.83(0.60,1.14)	0.61(0.45,0.81)	0.60(0.42,0.86)
Q4	58/707	0.43(0.30,0.62)	0.43(0.30,0.63)	0.47(0.29,0.77)	0.40(0.30,0.54)	0.45(0.32,0.63)	0.52(0.32,0.84)	1.06(0.75,1.49)	0.65(0.47,0.91)	0.51(0.29,0.89)
P trend		< 0.0001	< 0.0001	0.002	< 0.0001	< 0.0001	0.013	0.985	0.003	0.012

Model 1: Unadjusted model

Model 2: Adjusted for age, sex, and race

Model 3: Additionally adjusted for education, marital status, poverty, total energy intake, smoking status, total cholesterol, triglycerides, HbA1c, BMI, history of hypertension, hyperlipidemia, CKD, and hypoglycemic drugs

The specific range for the quantiles is consistent with Table 1

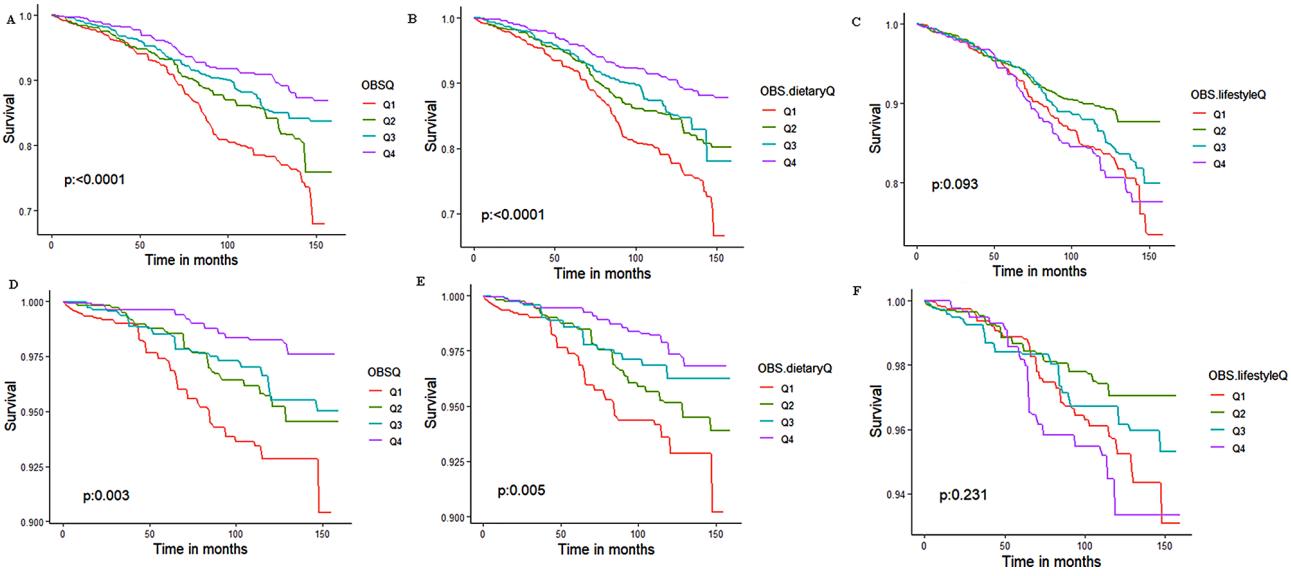


Fig. 3 Kaplan-Meier (K-M) survival curves according to OBS for all-cause mortality (**A**–**C**) and CVD mortality (**D**–**F**)

nutrients and 4 lifestyle factors [8], suggesting a crucial role of dietary modifications. As a result, diabetic populations with higher dietary and total OBS had lower risk of all-cause and cardiovascular mortality.

In our study, although the results of lifestyle OBS in all-cause and CVD-related mortality were not the same, the results of dietary and total OBS were consistent, suggesting that increasing the total intake of certain nutrients may be beneficial. Although the OBS components are numerous, they are easier to obtain, and calculating the OBSs can help clinicians assess patients' antioxidant levels more comprehensively at an early stage and determine their prognosis in an integrated and holistic manner.

Subgroup analyses showed that the correlation between OBS and all-cause mortality differed significantly concerning educational level, and our interaction test results indicated that the negative correlation effect between OBS and all-cause mortality was more pronounced in more educated populations. Our findings also suggest that the correlation between OBS and CVD-related mortality differs significantly concerning the history of CKD, and our interaction test results indicated that the negative correlation between OBS and CVD-related mortality is more prominent in diabetic populations without CKD. We know that CKD is an essential cause of CVD-related mortality [49], and there is no doubt that people with DM and concurrent CKD or diabetic nephropathy are at an increased risk of mortality than people with diabetes alone, explaining the results of our subgroup analyses. In addition, we stratified our analyses according to CVD subgroups, and interaction test results indicated no significant differences in the correlation between OBS and all-cause and CVD-related mortality concerning subgroups at increased risk of CVD. Of course, many clinical studies are warranted to assess the impact of high OBS on the health of normal populations.

This study is notable for selecting a large number of people from the US population to study the relationship between OBS and CVD and mortality. A wide range of potential covariates was also adjusted for in the study. Several statistical methods were used to minimize bias and validate the results, while we also performed categorical analyses to assess possible interactions between dietary and lifestyle OBS and mortality risk. However, the current study has several limitations. First, only the diabetic population was considered, and the pre-diabetic population was excluded from the analysis. However, future studies on the pre-diabetic population are warranted. Second, although the OBS consists of 20 components, it is still challenging to include all dietary and lifestyle exposures associated with oxidative stress, and there may be unspecified nutritional or lifestyle factors associated with oxidative stress that still need to be included. Third, the OBS dietary component was derived from self-reported data from the 24 h, and only one 24 h was used; therefore, it may be susceptible to measurement error and bias and may not account for daily dietary changes, leading to imprecise estimates. Finally, it is unknown whether our findings can be generalized to other regions of the United States and other countries, despite the large sample size.

Table 4 Associations between OBS and all-cause, CVD mortality stratified by age, gender, race, education, poverty level, HbA1c, diabetes drug use, history of hypertension, hyperlipidemia, CKD, and CVD prevalence subgroups. Hazard ratios were adjusted for age, sex, race, education, marital status, poverty, total energy intake, smoking status, total cholesterol, triglycerides, HbA1c, BMI, history of hypertension, hyperlipidemia, CKD, and hypoglycemic drugs

	All-cause mortality	**CVD mortality**		**All-cause mortality**	**CVD mortality**
	HR (95%CI) *p* for trend	**HR (95%CI) *p* for trend**		**HR (95%CI) *p* for trend**	**HR (95%CI) *p* for trend**
Gender			Age, years		
Female			< 60		
Q1	1.00 (ref)	1.00 (ref)	Q1	1.00 (ref)	1.00 (ref)
Q2	1.01 (0.59,1.74)	0.80 (0.64,0.99)	Q2	1.77 (0.77,4.04)	0.95 (0.77,1.17)
Q3	1.09 (0.60,1.97)	0.75 (0.61,0.93)	Q3	1.92 (0.62,5.96)	0.94 (0.77,1.14)
Q4	0.64 (0.30,1.40) 0.309	0.62 (0.42,0.90) 0.013	Q4	1.13 (0.29,4.36) 0.755	0.77 (0.57,1.04) 0.097
Male			≥ 60		
Q1	1.00 (ref)	1.00 (ref)	Q1	1.00 (ref)	1.00 (ref)
Q2	0.81 (0.51,1.30)	0.98 (0.79,1.22)	Q2	0.72 (0.48,1.08)	0.85 (0.71,1.02)
Q3	0.69 (0.44,1.08)	0.90 (0.73,1.12)	Q3	0.71 (0.48,1.05)	0.78 (0.66,0.93)
Q4	0.40 (0.22,0.74) 0.002	0.79 (0.61,1.02) 0.051	Q4	0.46 (0.26,0.81) 0.005	0.73 (0.58,0.92) 0.006
p for interaction	0.84	0.784	*p* for interaction	0.221	0.429
Race			Education, years		
Non-Hispanic White			< 12		
Q1	1.00 (ref)	1.00 (ref)	Q1	1.00 (ref)	1.00 (ref)
Q2	0.80 (0.49,1.30)	0.89 (0.73,1.07)	Q2	0.72 (0.45,1.13)	0.91 (0.74,1.13)
Q3	0.69 (0.47,1.04)	0.84 (0.70,1.01)	Q3	0.98 (0.56,1.70)	0.83 (0.68,1.02)
Q4	0.38 (0.21,0.67) < 0.0001	0.69 (0.53,0.90) 0.004	Q4	0.37 (0.20,0.69) 0.015	0.64 (0.42,0.98) 0.03
Non-Hispanic Black			≥ 12		
Q1	1.00 (ref)	1.00 (ref)	Q1	1.00 (ref)	1.00 (ref)
Q2	1.25 (0.69,2.29)	0.90 (0.73,1.10)	Q2	0.90 (0.54,1.52)	0.84 (0.68,1.03)
Q3	2.49 (1.20,5.19)	0.81 (0.64,1.02)	Q3	0.51 (0.27,0.95)	0.79 (0.66,0.94)
Q4	1.94 (0.84,4.45) 0.024	0.84 (0.62,1.14) 0.155	Q4	0.47 (0.22,0.98) 0.014	0.70 (0.57,0.86) 0.002
Mexican American			*p* for interaction	0.019	0.4
Q1	1.00 (ref)	1.00 (ref)	HbA1c, %		
Q2	0.71 (0.28,1.78)	1.16 (0.88,1.52)	< 7		
Q3	0.38 (0.07,2.23)	1.06 (0.78,1.44)	Q1	1.00 (ref)	1.00 (ref)
Q4	0.24 (0.03,1.89) 0.17	1.21 (0.80,1.81) 0.581	Q2	1.07 (0.68,1.68)	0.86 (0.72,1.03)
Other			Q3	0.93 (0.59,1.46)	0.87 (0.73,1.04)
Q1	1.00 (ref)	1.00 (ref)	Q4	0.56 (0.30,1.03) 0.057	0.76 (0.58,1.00) 0.074
Q2	0.94 (0.35,2.50)	0.73 (0.58,0.92)	≥ 7		
Q3	1.15 (0.26,5.11)	0.82 (0.61,1.11)	Q1	1.00 (ref)	1.00 (ref)
Q4	1.15 (0.14,9.31) 0.837	0.85 (0.57,1.26) 0.741	Q2	0.72 (0.37,1.40)	0.90 (0.70,1.17)
p for interaction	0.751	0.26	Q3	0.78 (0.41,1.48)	0.67 (0.55,0.82)
Poverty level			Q4	0.33 (0.14,0.76) 0.021	0.57 (0.43,0.76) < 0.0001
Low income			*p* for interaction	0.791	0.08
Q1	1.00 (ref)	1.00 (ref)			
Q2	0.69 (0.44,1.09)	0.84 (0.71,0.98)			
Q3	0.58 (0.29,1.17)	0.82 (0.67,1.01)			
Q4	0.44 (0.23,0.83) 0.012	0.85 (0.63,1.13) 0.162	Diabetes drug use		
Middle income			No		
Q1	1.00 (ref)	1.00 (ref)	Q1	1.00 (ref)	1.00 (ref)
Q2	0.91 (0.53,1.59)	0.88 (0.66,1.18)	Q2	0.27 (0.08,0.96)	0.97 (0.71,1.33)
Q3	1.09 (0.65,1.85)	0.96 (0.73,1.25)	Q3	0.74 (0.20,2.77)	0.82 (0.61,1.11)
Q4	0.39 (0.21,0.73) 0.019	0.69 (0.52,0.91) 0.016	Q4	0.23 (0.03,2.17) 0.344	0.78 (0.54,1.12) 0.097
High income			Yes		
Q1	1.00 (ref)	1.00 (ref)	Q1	1.00 (ref)	1.00 (ref)
Q2	0.76 (0.34,1.69)	0.92 (0.72,1.17)	Q2	0.96 (0.63,1.45)	0.89 (0.75,1.05)
Q3	0.46 (0.18,1.20)	0.81 (0.65,1.00)	Q3	0.80 (0.55,1.16)	0.89 (0.77,1.03)

Table 4 (continued)

	All-cause mortality	CVD mortality		All-cause mortality	CVD mortality
	HR (95%CI) *p* for trend	HR (95%CI) *p* for trend		HR (95%CI) *p* for trend	HR (95%CI) *p* for trend
Q4	0.45 (0.13,1.59) 0.189	0.76 (0.56,1.03) 0.051	Q4	0.49 (0.29,0.83) 0.004	0.76 (0.60,0.96) 0.02
p for interaction	0.256	0.312	*p* for interaction	0.232	0.472
Hyperlipidemia			Hypertension		
No			No		
Q1	1.00 (ref)	1.00 (ref)	Q1	1.00 (ref)	1.00 (ref)
Q2	0.46 (0.20,1.09)	1.13 (0.72,1.76)	Q2	0.96 (0.44,2.08)	0.86 (0.64,1.15)
Q3	0.79 (0.23,2.76)	1.15 (0.77,1.73)	Q3	1.15 (0.56,2.36)	0.87 (0.65,1.16)
Q4	0.55 (0.17,1.71) 0.399	0.93 (0.53,1.63) 0.753	Q4	0.38 (0.12,1.19) 0.156	0.70 (0.49,0.99) 0.055
Yes			Yes		
Q1	1.00 (ref)	1.00 (ref)	Q1	1.00 (ref)	1.00 (ref)
Q2	0.90 (0.57,1.42)	0.87 (0.75,1.02)	Q2	0.88 (0.57,1.37)	0.94 (0.80,1.09)
Q3	0.78 (0.51,1.19)	0.83 (0.72,0.95)	Q3	0.73 (0.50,1.08)	0.87 (0.75,1.01)
Q4	0.45 (0.25,0.81) 0.006	0.73 (0.58,0.93) 0.008	Q4	0.48 (0.29,0.80) 0.002	0.81 (0.65,0.99) 0.029
p for interaction	0.694	0.31	*p* for interaction	0.39	0.315
CKD			CVD Angina		
No			No		
Q1	1.00 (ref)	1.00 (ref)	Q1	1.00 (ref)	1.00 (ref)
Q2	1.03 (0.55,1.94)	0.69 (0.50,0.95)	Q2	0.90 (0.58,1.40)	0.93 (0.79,1.10)
Q3	0.78 (0.42,1.44)	0.65 (0.44,0.96)	Q3	0.83 (0.55,1.24)	0.88 (0.77,1.01)
Q4	0.56 (0.23,1.38) 0.195	0.32 (0.19,0.56) < 0.0001	Q4	0.49 (0.27,0.88) 0.013	0.78 (0.63,0.97) 0.017
Yes			Yes		
Q1	1.00 (ref)	1.00 (ref)	Q1	1.00 (ref)	1.00 (ref)
Q2	0.79 (0.52,1.22)	0.91 (0.76,1.08)	Q2	0.16 (0.03,0.77)	0.29 (0.12,0.67)
Q3	0.80 (0.50,1.30)	0.86 (0.75,0.99)	Q3	0.08 (0.01,0.54)	0.61 (0.31,1.21)
Q4	0.43 (0.22,0.81) 0.014	0.76 (0.59,0.97) 0.02	Q4	0.02 (0.00,0.21) < 0.001	0.37 (0.17,0.84) 0.223
p for interaction	0.803	0.031	*p* for interaction	0.785	0.248
Heart attack			Stroke		
No			No		
Q1	1.00 (ref)	1.00 (ref)	Q1	1.00 (ref)	1.00 (ref)
Q2	0.96 (0.63,1.45)	0.90 (0.76,1.06)	Q2	0.74 (0.50,1.10)	0.92 (0.79,1.08)
Q3	0.98 (0.63,1.53)	0.87 (0.75,1.00)	Q3	0.60 (0.43,0.82)	0.88 (0.77,1.00)
Q4	0.52 (0.29,0.94) 0.042	0.75 (0.61,0.93) 0.006	Q4	0.42 (0.29,0.61) < 0.0001	0.77 (0.62,0.94) 0.007
Yes			Yes		
Q1	1.00 (ref)	1.00 (ref)	Q1	1.00 (ref)	1.00 (ref)
Q2	0.66 (0.35,1.24)	1.17 (0.49,2.84)	Q2	1.70 (0.66,4.34)	1.02 (0.44,2.40)
Q3	0.22 (0.08,0.60)	1.47 (0.71,3.05)	Q3	1.11 (0.45,2.78)	1.30 (0.58,2.91)
Q4	0.20 (0.06,0.72) 0.004	1.29 (0.72,2.29) 0.375	Q4	0.57 (0.14,2.31) 0.325	1.48 (0.36,6.12) 0.423
p for interaction	0.204	0.827	*p* for interaction	0.398	0.633
CHF			CHD		
No			No		
Q1	1.00 (ref)	1.00 (ref)	Q1	1.00 (ref)	1.00 (ref)
Q2	0.85 (0.55,1.31)	0.95 (0.81,1.11)	Q2	0.97 (0.66,1.44)	0.89 (0.75,1.05)
Q3	0.87 (0.57,1.31)	0.33 (0.82,1.05)	Q3	0.92 (0.58,1.46)	0.86 (0.75,0.99)
Q4	0.53 (0.32,0.89) 0.021	0.84 (0.68,1.03) 0.08	Q4	0.55 (0.30,1.00) 0.055	0.75 (0.61,0.93) 0.007
Yes			Yes		
Q1	1.00 (ref)	1.00 (ref)	Q1	1.00 (ref)	1.00 (ref)
Q2	0.89 (0.37,2.10)	0.76 (0.44,1.29)	Q2	0.78 (0.32,1.90)	0.95 (0.51,1.74)
Q3	0.27 (0.09,0.84)	1.15 (0.56,2.37)	Q3	0.55 (0.19,1.76)	0.98 (0.51,1.88)

Table 4 (continued)

	All-cause mortality	CVD mortality		All-cause mortality	CVD mortality
	HR (95%CI) *p* for trend	HR (95%CI) *p* for trend		HR (95%CI) *p* for trend	HR (95%CI) *p* for trend
Q4	0.11 (0.03,0.45) < 0.001	1.44 (0.68,3.04) 0.23	Q4	0.24 (0.09,0.63) 0.008	0.83 (0.41,1.68) 0.657
p for interaction	0.713	0.104	*p* for interaction	0.739	0.645

Model 1: Unadjusted model

Model 2: Adjusted for age, sex, and race

Model 3: Additionally adjusted for education, marital status, poverty, total energy intake, smoking status, total cholesterol, triglycerides, HbA1c, BMI, history of hypertension, history of hyperlipidemia, history of CKD, and hypoglycemic drugs

The specific range for the quantiles is consistent with Table 1

Conclusions

Although OBS is not very useful for assessing CVD prevalence outcomes, higher OBS was significantly associated with lower all-cause and CVD-related mortality, suggesting that maintaining adequate OBSs may reduce mortality in patients with DM.

Acknowledgements
The authors express their gratitude to the participants and staff of the NHANES for their invaluable contributions to this study.

Author contributions
Conceptualization was performed by Hao Wang and Jin-Song Xu; data curation was performed by Yan-Lin Chen and Yan Xu; formal analysis was performed by Yan-Lin Chen and Xiang-Ming Li; funding acquisition was performed by Jin-Song Xu and Yan Xu; methodology was performed by Hao Wang, Xiang-Ming Li, and Qi Wu; validation was performed by Xiang-Ming Li and Qi Wu; writing (original draft) was performed by Hao Wang; writing (review and editing) was performed by Jin-Song Xu and Yan Xu. All authors reviewed the manuscript.

Funding
This work was supported by grants from National Natural Science Foundation of China (No. 82360094, No. 82360100).

Data availability
The datasets used in this manuscript are publicly available from the NHANES website: https://www.cdc.gov/nchs/nhanes/index.htm.

Declarations

Ethical approval
The Ethics Review Board of the National Center for Health Statistics has approved the survey plan and study protocol; therefore, this study has been performed following the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Department of Cardiology, The Second Affiliated Hospital, Jiangxi Medical College, Nanchang University, Nanchang 330006, China
[2]Department of Guangdong Cardiovascular Institute, Guangdong Provincial People's Hospital (Guangdong Academy of Medical Sciences), Southern Medical University, Guangzhou 510080, China
[3]Department of The Second Hospital, Cheeloo College of Medicine, Shandong University, Jinan 250033, China
[4]Health Management Center, Ganjiang New Area People's Hospital, Nanchang 330006, China

Received: 25 February 2024 / Accepted: 18 September 2024
Published online: 27 September 2024

References

1. Zhang R, Qin X, Zhang T, Li Q, Zhang J, Zhao J. Astragalus Polysaccharide improves insulin sensitivity via AMPK activation in 3T3-L1 adipocytes. Molecules 2018;23.
2. Cho NH, Shaw JE, Karuranga S, et al. IDF Diabetes Atlas: global estimates of diabetes prevalence for 2017 and projections for 2045. Diabetes Res Clin Pract. 2018;138:271–81.
3. Harding JL, Pavkov ME, Magliano DJ, Shaw JE, Gregg EW. Global trends in diabetes complications: a review of current evidence. Diabetologia. 2019;62:3–16.
4. Strain WD, Paldanius PM. Diabetes, cardiovascular disease and the microcirculation. Cardiovasc Diabetol. 2018;17:57.
5. Tangvarasittichai S. Oxidative stress, insulin resistance, dyslipidemia and type 2 diabetes mellitus. World J Diabetes 2015;6.
6. Henriksen EJ, Diamond-Stanic MK, Marchionne EM. Oxidative stress and the etiology of insulin resistance and type 2 diabetes. Free Radic Biol Med. 2011;51:993–9.
7. Scott JA, King GL. Oxidative stress and antioxidant treatment in diabetes. Ann N Y Acad Sci. 2006;1031:204–13.
8. Zhang W, Peng SF, Chen L, Chen HM, Cheng XE, Tang YH. Association between the oxidative balance score and telomere length from the National Health and Nutrition Examination Survey 1999–2002. Oxid Med Cell Longev. 2022;2022:1345071.
9. Xu Z, Xue Y, Wen H, Chen C. Association of oxidative balance score and lung health from the National Health and Nutrition Examination Survey 2007–2012. Front Nutr. 2022;9:961950.
10. Kwon YJ, Park HM, Lee JH. Inverse Association between oxidative balance score and incident type 2 diabetes Mellitus. Volume 15. Nutrients; 2023.
11. Wu C, Ren C, Song Y, Gao H, Pang X, Zhang L. Gender-specific effects of oxidative balance score on the prevalence of diabetes in the US population from NHANES. Front Endocrinol (Lausanne). 2023;14:1148417.
12. Golmohammadi M, Ayremlou P, Zarrin R. Higher oxidative balance score is associated with better glycemic control among Iranian adults with type-2 diabetes. Int J Vitam Nutr Res. 2021;91:31–9.
13. Kong SY, Goodman M, Judd S, Bostick RM, Flanders WD, McClellan W. Oxidative balance score as predictor of all-cause, cancer, and noncancer mortality in a biracial US cohort. Ann Epidemiol. 2015;25:256–62. e1.
14. Zhan F, Lin G, Duan K, Huang B, Chen L, Ni J. Higher oxidative balance score decreases risk of stroke in US adults: evidence from a cross-sectional study. Front Cardiovasc Med. 2023;10:1264923.
15. Johnson CL, Paulose-Ram R, Ogden CL, et al. National health and nutrition examination survey: analytic guidelines, 1999–2010. Vital Health Stat. 2013;2(161):1–24.
16. Piercy KL, Troiano RP, Ballard RM, et al. Phys Activity Guidelines Americans JAMA. 2018;320:2020–8.
17. Peters SAE, Muntner P, Woodward M. Sex differences in the prevalence of, and trends in, Cardiovascular Risk factors, treatment, and control in the United States, 2001 to 2016. Circulation. 2019;139:1025–35.
18. National Cholesterol Education Program (NCEP). Expert Panel on detection, evaluation, and treatment of high blood cholesterol in adults (Adult Treatment Panel III). Third report of the National Cholesterol Education Program (NCEP) Expert Panel on detection, evaluation, and treatment of high blood

cholesterol in adults (Adult Treatment Panel III) final report. Circulation. 2002;106(25):3143–421.
19. Kidney Disease. Improving global outcomes glomerular diseases Work G. KDIGO 2021 Clinical Practice Guideline for the management of glomerular diseases. Kidney Int. 2021;100:S1–276.
20. Xu C, Liang J, Xu S, Liu Q, Xu J, Gu A. Increased serum levels of aldehydes are associated with cardiovascular disease and cardiovascular risk factors in adults. J Hazard Mater. 2020;400:123134.
21. Liu X, Wang Y, Liu X, et al. Higher oxidative balance scores are associated with lower nonalcoholic fatty liver disease and not with fibrosis in US adults. Nutr Metab Cardiovasc Dis. 2023;33:2488–96.
22. Kim J, Lee J, Choi IJ, Kim YI, Kim J. Gastric cancer risk is reduced by a predominance of antioxidant factors in the oxidative balance: a hospital-based case-control study in Korea. Epidemiol Health. 2022;44:e2022089.
23. Lee JH, Son DH, Kwon YJ. Association between oxidative balance score and new-onset hypertension in adults: a community-based prospective cohort study. Front Nutr. 2022;9:1066159.
24. Chen X, Wang C, Dong Z, Luo H, Ye C, Li L, Wang E. Interplay of sleep patterns and oxidative balance score on total cardiovascular disease risk: insights from the National Health and Nutrition Examination Survey 2005–2018. J Glob Health. 2023;13:04170.
25. Saura-Calixto F. Dietary fiber as a carrier of dietary antioxidants: an essential physiological function. J Agric Food Chem. 2011;59:43–9.
26. Ashoori M, Saedisomeolia A. Riboflavin (vitamin B(2)) and oxidative stress: a review. Br J Nutr. 2014;111:1985–91.
27. Rao AV, Rao LG. Carotenoids and human health. Pharmacol Res. 2007;55:207–16.
28. Padayatty SJ, Katz A, Wang Y, et al. Vitamin C as an antioxidant: evaluation of its role in disease prevention. J Am Coll Nutr. 2003;22:18–35.
29. Kojo S, Vitamin C. Basic metabolism and its function as an index of oxidative stress. Curr Med Chem. 2004;11(8):1041–64.
30. Burton GW, Ingold KU. Vitamin E as an in vitro and in vivo antioxidant. Ann N Y Acad Sci. 1989;570:7–22.
31. Miyazawa T, Burdeos GC, Itaya M, Nakagawa K, Miyazawa T, Vitamin E. Regulatory Redox interactions. IUBMB Life. 2019;71:430–41.
32. Ji LL, Gomez-Cabrera MC, Vina J. Exercise and hormesis: activation of cellular antioxidant signaling pathway. Ann N Y Acad Sci. 2006;1067:425–35.
33. El Assar M, Alvarez-Bustos A, Sosa P, Angulo J, Rodriguez-Manas L. Effect of Physical Activity/Exercise on oxidative stress and inflammation in muscle and vascular aging. Int J Mol Sci 2022;23.
34. Tappel A. Heme of consumed red meat can act as a catalyst of oxidative damage and could initiate colon, breast and prostate cancers, heart disease and other diseases. Med Hypotheses. 2007;68:562–4.
35. Puntarulo S. Iron, oxidative stress and human health. Mol Aspects Med. 2005;26:299–312.
36. Furukawa S, Fujita T, Shimabukuro M, et al. Increased oxidative stress in obesity and its impact on metabolic syndrome. J Clin Invest. 2004;114:1752–61.
37. van der Vaart H, Postma DS, Timens W, ten Hacken NH. Acute effects of cigarette smoke on inflammation and oxidative stress: a review. Thorax. 2004;59:713–21.
38. Wu D, Zhai Q, Shi X. Alcohol-induced oxidative stress and cell responses. J Gastroenterol Hepatol. 2006;21(Suppl 3):S26–9.
39. Das SK, Vasudevan DM. Alcohol-induced oxidative stress. Life Sci. 2007;81:177–87.
40. Opara EC. Role of oxidative stress in the etiology of type 2 diabetes and the effect of antioxidant supplementation on glycemic control. J Investig Med. 2004;52(1):19–23.
41. Caturano A, D'Angelo M, Mormone A, et al. Oxidative stress in type 2 diabetes: impacts from Pathogenesis to lifestyle modifications. Curr Issues Mol Biol. 2023;45:6651–66.
42. Leh HE, Lee LK, Lycopene. A potent antioxidant for the amelioration of type II diabetes Mellitus. Molecules 2022;27.
43. Martucci M, Ostan R, Biondi F, et al. Mediterranean diet and inflammaging within the hormesis paradigm. Nutr Rev. 2017;75:442–55.
44. Aune D, Keum N, Giovannucci E, et al. Dietary intake and blood concentrations of antioxidants and the risk of cardiovascular disease, total cancer, and all-cause mortality: a systematic review and dose-response meta-analysis of prospective studies. Am J Clin Nutr. 2018;108:1069–91.
45. Liu Y, Geng T, Wan Z, et al. Associations of serum folate and vitamin B12 levels with Cardiovascular Disease Mortality among patients with type 2 diabetes. JAMA Netw open. 2022;5:e2146124.
46. Wang S, Wang Y, Wan X, et al. Cobalamin Intake and related biomarkers: Examining associations with mortality risk among adults with type 2 diabetes in NHANES. Diabetes Care. 2022;45:276–84.
47. Barr EL, Zimmet PZ, Welborn TA, et al. Risk of cardiovascular and all-cause mortality in individuals with diabetes mellitus, impaired fasting glucose, and impaired glucose tolerance: the Australian diabetes, obesity, and Lifestyle Study (AusDiab). Circulation. 2007;116:151–7.
48. Mao Z, Prizment AE, Lazovich D, Bostick RM. Associations of dietary and lifestyle oxidative balance scores with mortality risk among older women: the Iowa women's Health Study. Eur J Nutr. 2021;60:3873–86.
49. Collaboration GBDCKD. Global, regional, and national burden of chronic kidney disease, 1990–2017: a systematic analysis for the global burden of Disease Study 2017. Lancet (London England). 2020;395:709–33.

Publisher's note