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Research article

Association between the oxidative balance score and estimated glomerular filtration rate: 2007–2018 NHANES

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ABSTRACT

Oxidative stress is closely associated with the estimated glomerular filtration rate (eGFR) levels. A comprehensive indicator for evaluating dietary and lifestyle exposures to oxidative stress is the Oxidative Balance Score (OBS), with higher OBS suggesting more substantial antioxidant exposures. The aim of this study is to explore the relationship between OBS and eGFR levels. A total of 20,285 subjects were selected from the National Health and Nutrition Examination Survey (NHANES) from 2007 to 2018. One-way and multifactorial linear regression analyses were used to assess the association of OBS with eGFR. The relationship between OBS and eGFR levels was also assessed using restricted cubic splines (RCS) analysis. OBS levels were significantly and positively correlated with eGFR levels, and eGFR values were more susceptible to OBS in males than in females. Our findings suggest that higher OBS scores may be associated with higher eGFR levels, highlighting the importance of adhering to an antioxidant diet and lifestyle, which can help prevent kidney disease.

1. Introduction

Chronic kidney disease (CKD) represents a major global health burden, affecting approximately 10–13 % of the world's population, with increasing prevalence due to aging populations and rising incidence of risk factors such as hypertension, diabetes, and obesity [1]. In the United States, more than 15 % of men and more than 5 % of women will develop kidney stone disease (KSD) by the age of 70 years. more than 50 % of patients with KSD will have a recurrence within a decade [2–4]. The estimated glomerular filtration rate (eGFR) is widely used as a key indicator of kidney function [5–7], and its decline is closely linked to CKD progression and associated adverse outcomes, including cardiovascular disease and mortality. Identifying modifiable factors that influence eGFR levels is essential for the development of preventative strategies aimed at preserving kidney function and mitigating CKD risk. A decrease in eGFR may lead to an increase in the concentration of calcium, phosphate, and uric acid in the urine, and these changes can promote stone formation.

Oxidative stress, characterized by an imbalance between reactive oxygen species (ROS) production and antioxidant defenses, plays a pivotal role in the pathogenesis and progression of CKD [8,9]. Excessive ROS can lead to cellular damage, inflammation, and fibrosis,

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ultimately contributing to glomerular and tubular injury [10,11]. Emerging evidence suggests that lifestyle factors, including diet, physical activity, and smoking, significantly influence oxidative stress levels, which in turn affect renal function. The Oxidative Balance Score (OBS) has been developed as a composite measure to quantify overall exposure to oxidative stress-related factors, encompassing both pro-oxidant and antioxidant influences from diet and lifestyle. Higher OBS values indicate a greater antioxidant status, which may offer protective effects against oxidative damage and its associated disease processes. Studies have demonstrated that a high OBS is associated with a reduced risk of congenital anomalies such as cleft lip, limb deficiencies, and anencephaly [12,13], as well as a lower prevalence of diabetic kidney disease, CKD and hypertension [14]. While previous studies have highlighted the impact of oxidative stress on renal health, the specific association between OBS and eGFR remains underexplored. Given the complexity of oxidative stress and its interplay with kidney function, it is crucial to understand how lifestyle-related oxidative balance influences eGFR, particularly in diverse populations. Moreover, sex differences in oxidative stress responses have been observed, potentially leading to differential effects on renal function between males and females [15]. Therefore, this study aims to investigate the relationship between OBS and eGFR using data from the National Health and Nutrition Examination Survey (NHANES) from 2007 to 2018. By assessing this association, we aim to elucidate the potential protective role of antioxidant-rich diets and lifestyles in maintaining kidney function. Furthermore, we explore sex-specific differences to provide a comprehensive understanding of how oxidative balance affects renal health across different demographic groups. Understanding these associations may guide public health recommendations and interventions designed to reduce oxidative stress and its adverse impacts on kidney function.

2. Materials and methods

2.1. Study design

This cross-sectional study included participants from the consecutive nationally representative National Health and Nutrition Examination Survey (NHANES) conducted from 2007 to 2018. Of the 59,842 participants in NHANES 2007–2018, individuals were excluded if (1) they were missing any OBS component data (dietary fiber n = 2437; nicotine n = 14; Body mass index (BMI) n = 356; MET n = 10315); (2) data on serum creatinine were missing (n = 21919); (3) they lacked marital status (n = 367) or documentation of comorbidities (n = 149). Ultimately, a total of 20,285 participants were included in the study, as depicted in Fig. 1.

2.2. Estimated glomerular filtration rate (eGFR)

For the calculation of eGFR, patients' serum creatinine was converted using the well-recognized CKD-EPI formula [16]. Serum creatinine is recorded in the "Laboratory Data", and eGFR is categorized into four groups: eGFR$<$ 30, 30 $\leq$eGFR $<$60, 60 $\leq$ eGFR $<$90, and eGFR$\geq$90.

2.3. Exposure variables

Sixteen nutritional and four lifestyle factors (including 16 antioxidants and 4 pro-oxidants) were selected for inclusion in the calculation, as documented in multiple studies. The sixteen nutrients include dietary fiber, carotene, riboflavin, niacin, vitamin B6, total folate, vitamin B12, vitamin C, vitamin E, calcium, magnesium, zinc, copper, selenium, total fat, and iron. The lifestyle factors includes physical activity, BMI, alcohol consumption and smoking. The assessment of smoking was substituted with cotinine measurements. For alcohol consumption: $\geq$30 g/d for heavy drinkers, 0–30 g/d for non-heavy drinkers and non-drinkers for males; for

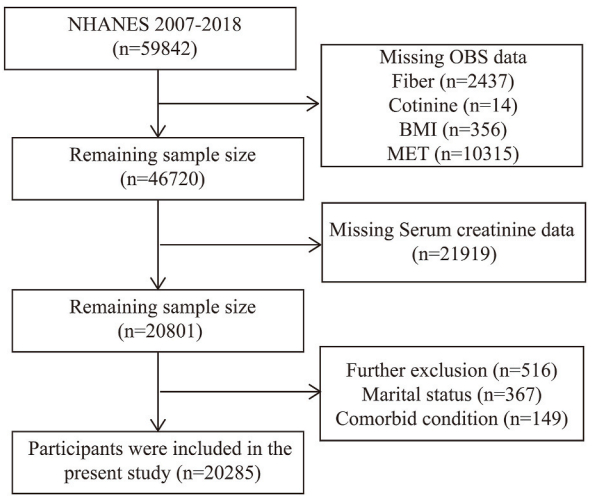

Fig. 1. Flowchart of participants included in analyses.

heavy drinkers ≥15 g/d, 0–15 g/d for non-heavy drinkers and non-drinkers for females [3,4]. The OBS allocation scheme is shown in Table 1, for heavy drinking, non-heavy drinking and non-drinking groups were assigned scores of 0, 1 and 2, respectively. The remaining components were also categorized into three groups based on gender specificity, and antioxidants were assigned scores ranging from 0 to 2 for the groups ranging from tertile 1 to tertile 3, respectively. The scoring for oxidants was reversed, assigning a

Table 1
Ingredients that make up the oxidative balance score (OBS).

Dietary OBS components			
Dietary fiber (g/d)	0 = low (1st tertile)	1 = medium (2nd tertile)	2 = high (3rd tertile)
Male	<11.90	11.90–20.10	>20.10
Female	<10.10	10.10–16.70	>16.70
Carotene (RE/d)	0 = low (1st tertile)	1 = medium (2nd tertile)	2 = high (3rd tertile)
Male	<404.00	404.00–1429.33	>1429.33
Female	<382.00	382.00–1610.00	>1610.00
Riboflavin (mg/d)	0 = low (1st tertile)	1 = medium (2nd tertile)	2 = high (3rd tertile)
Male	<1.61	1.61–2.55	>2.55
Female	<1.26	1.26–1.94	>1.94
Niacin (mg/d)	0 = low (1st tertile)	1 = medium (2nd tertile)	2 = high (3rd tertile)
Male	<20.76	20.76–32.24	>32.24
Female	<14.98	14.98–22.91	>22.91
Vitamin B6 (mg/d)	0 = low (1st tertile)	1 = medium (2nd tertile)	2 = high (3rd tertile)
Male	<1.55	1.55–2.50	>2.50
Female	<1.14	1.14–1.85	>1.85
Total folate (mcg/d)	0 = low (1st tertile)	1 = medium (2nd tertile)	2 = high (3rd tertile)
Male	<300.00	300.00–491.00	>491.00
Female	<235.00	235.00–381.00	>381.00
Vitamin B12 (mcg/d)	0 = low (1st tertile)	1 = medium (2nd tertile)	2 = high (3rd tertile)
Male	<3.15	3.15–6.16	>6.16
Female	<2.18	2.18–4.31	>4.31
Vitamin C (mg/d)	0 = low (1st tertile)	1 = medium (2nd tertile)	2 = high (3rd tertile)
Male	<28.70	28.70–92.43	>92.43
Female	<27.60	27.60–84.30	>84.30
Vitamin E (ATE) (mg/d)	0 = low (1st tertile)	1 = medium (2nd tertile)	2 = high (3rd tertile)
Male	<5.43	5.43–9.57	>9.57
Female	<4.53	4.53–7.86	>7.86
Calcium (mg/d)	0 = low (1st tertile)	1 = medium (2nd tertile)	2 = high (3rd tertile)
Male	<686.00	686.00–1161.00	>1161.00
Female	<566.00	566.00–946.00	>946.00
Magnesium (mg/d)	0 = low (1st tertile)	1 = medium (2nd tertile)	2 = high (3rd tertile)
Male	<237.00	237.00–357.00	>357.00
Female	<192.00	192.00–284.00	>284.00
Zinc (mg/d)	0 = low (1st tertile)	1 = medium (2nd tertile)	2 = high (3rd tertile)
Male	<8.84	8.84–14.22	>14.22
Female	<6.53	6.53–10.26	>10.26
Copper (mg/d)	0 = low (1st tertile)	1 = medium (2nd tertile)	2 = high (3rd tertile)
Male	<0.95	0.95–1.45	>1.45
Female	<0.78	0.78–1.18	>1.18
Selenium (mcg/d)	0 = low (1st tertile)	1 = medium (2nd tertile)	2 = high (3rd tertile)
Male	<95.80	95.80–147.20	>147.20
Female	<70.00	70.00–108.10	>108.10
Total fat (g/d)	0 = low (3rd tertile)	1 = medium (2nd tertile)	2 = high (1st tertile)
Male	>103.38	64.57–103.38	<64.57
Female	>78.52	49.23–78.52	<49.23
Iron (mg/d)	0 = low (3rd tertile)	1 = medium (2nd tertile)	2 = high (1st tertile)
Male	>18.25	11.60–18.25	<11.60
Female	>13.90	8.89–13.90	<8.89
Lifestyle OBS components			
Physical activity (MET-minute/week)	0 = low (1st tertile)	1 = medium (2nd tertile)	2 = high (3rd tertile)
Male	<240.00	240.00–920.00	>920.00
Female	<170.00	170.00–530.00	>530.00
Alcohol (g/d)	0 = low (3rd tertile)	1 = medium (2nd tertile)	2 = high (1st tertile)
Male	>24.01	12.01–24.01	<12.01
Female	>19.85	9.93–19.85	<9.93
Body mass index (kg/m2)	0 = low (3rd tertile)	1 = medium (2nd tertile)	2 = high (1st tertile)
Male	>29.63	24.80–29.63	<24.80
Female	>31.00	24.70–31.00	<24.70
Cotinine (ng/mL)	0 = low (3rd tertile)	1 = medium (2nd tertile)	2 = high (1st tertile)
Male	>0.71	0.02–0.71	<0.02
Female	>0.10	0.02–0.10	<0.02

Low, medium, and high categories correspond to sex-specific 1st, 2nd, and 3rd tertiles.
Separate scoring for males and females.

score of 0 to the highest tertile and 2 to the lowest tertile. The final total OBS is calculated by summing the scores attributed to each component, with the higher OBS values indicating a greater antioxidant benefit.

2.4. Covariates

Based on previous research regarding the prevalence and prognosis of chronic kidney disease (CKD), we systematically examined the inclusion of relevant potential confounding factors [17,18]. The covariates included demographic information such as age, gender, race (Non-Hispanic White, Non-Hispanic Black, Mexican American, Other race/multiple races), marital status (Married/Living with partner, Widowed/Divorced/Separated/Never married), educational level (<High school, Completed high school, >High school), poverty income ratioa (Poor, Not poor). Health-related variables included diabetes, hypertension, kidney stone, renal failure and cardiovascular diseases (including heart failure, coronary artery disease, stroke, angina and heart attack). Hypertension was defined as an average systolic blood pressure (SBP) $\geq$ 140 mmHg and/or an average diastolic blood pressure (DBP) $\geq$ 90 mmHg or a self-reported diagnosis of hypertension combined with the use of antihypertensive medications [19,20]. Diabetes was defined by the following criteria: (a) a prior diagnosis of diabetes or current use of diabetes medications; (b) fasting blood glucose (FBG) $\geq$ 7.0 mmol/L; (c) glycated hemoglobin (HbA1C) $\geq$ 6.5 % [21]. Kidney stone, renal failure, heart failure, coronary artery disease, stroke, angina and heart attack were defned as diagnosis made by a doctor/specialist.

2.5. Statistical analysis

Statistical analyses were performed using the statistical software R version 4.3.1 (R Foundation for Statistical Computing, Vienna, Austria; http://www.r-project.org), and a two-sided P-value of <0.05 was considered significant. In descriptive statistics, continuous variables were expressed as means and standard deviations, while categorical variables were expressed as percentages. Comparisons of categorical variables between groups were performed using the chi-square test, and comparisons of continuous variables between groups were performed using the Kruskal-Wallis test. In this study, the continuous variable OBS was converted into a categorical variable according to quartiles, and the trend was assessed using the P value. Two models were applied in this study. Model 1 incorporated age, gender, race, marital status, educational level, poverty income ratioa, while Model 2 incorporated diabetes, hypertension, kidney stone, renal failure and cardiovascular diseases in addition to the factors in Model I. Finally, the relationship

Table 2
Characteristics of study participants (n = 20285).

Characteristic	All	OBS quartile				*P*-value
		Quartile 1	Quartile 2	Quartile 3	Quartile 4	
OBS, range	4–37	4–16	16–22	22–27	27–37	
OBS, mean (SD)	21.4 (7.0)	11.8 (2.5)	18.6 (1.7)	24.0 (1.4)	29.8 (2.2)	<0.001
Male (%)	10489 (51.7)	2450 (51.3)	2594 (51.9)	2585 (53.4)	2860 (50.4)	0.023
Female (%)	9796 (48.3)	2325 (48.7)	2406 (48.1)	2256 (46.6)	2809 (49.6)	
Age, mean (SD)	47.6 (17.2)	48.3 (17.7)	48.1 (17.2)	47.7 (17.0)	46.4 (16.8)	<0.001
Race, n (%)						<0.001
Non-Hispanic White	8849 (43.6)	1866 (39.1)	2194 (43.9)	2168 (44.8)	2621 (46.2)	
Non-Hispanic Black	4064 (20.0)	1412 (29.6)	1028 (20.6)	832 (17.2)	792 (14)	
Mexican American	2966 (14.6)	580 (12.1)	699 (14)	739 (15.3)	948 (16.7)	
Other race/multiple races	4406 (21.7)	917 (19.2)	1079 (21.6)	1102 (22.8)	1308 (23.1)	
Marital status, n (%)						<0.001
Married/Living with partner	12252 (60.4)	2580 (54.0)	2991 (59.8)	3044 (62.9)	3637 (64.1)	
Widowed/Divorced/Separated /Never married	8033 (39.6)	2195 (46.0)	2009 (40.2)	1797 (37.1)	2032 (35.9)	
Educational level, n (%)						<0.001
<High school	1652 (8.1)	462 (9.7)	440 (8.8)	375 (7.7)	375 (6.6)	
Completed high school	2551 (12.6)	770 (16.1)	638 (12.8)	569 (11.8)	574 (10.1)	
>High school	16082 (79.3)	3543 (74.2)	3922 (78.4)	3897 (80.5)	4720 (83.3)	
Poverty income ratioa, n (%)						<0.001
Poor	3767 (18.6)	1168 (24.5)	926 (18.5)	764 (15.8)	909 (16)	
Not poor	16518 (81.4)	3607 (75.5)	4074 (81.5)	4077 (84.2)	4760 (84)	
Diabetes, n (%)	2153 (10.6)	619 (13.1)	566 (11.3)	500 (10.38)	468 (8.14)	<0.001
Hypertension, n (%)	7877 (38.8)	2116 (44.8)	2029 (40.63)	1831 (38.0)	1901 (33.1)	<0.001
Kidney stone, n (%)	1813 (8.9)	473 (10.0)	481 (9.6)	415 (8.6)	444 (7.7)	<0.001
Renal failure, n (%)	523 (2.6)	164 (3.5)	138 (2.76)	113 (2.3)	108 (1.9)	<0.001
Cardiovascular diseases, n (%)	1699 (8.38)	570 (12.07)	419 (8.39)	356 (7.4)	354 (6.2)	<0.001
eGFR, mL/min/1.73 m2, Mean ± SD	83.1 ± 22.7	81.6 ± 23.8	82.5 ± 22.7	83.7 ± 22.7	84.3 ± 21.7	<0.001
eGFR, n (%)						<0.001
eGFR <30	211 (1.0)	80 (1.7)	62 (1.2)	46 (1)	23 (0.4)	
30≤ eGFR <60	2840 (14.0)	740 (15.5)	704 (14.1)	667 (13.8)	729 (12.9)	
60≤ eGFR <90	9674 (47.7)	2273 (47.6)	2429 (48.6)	2265 (46.8)	2707 (47.8)	
eGFR≥90	7560 (37.3)	1682 (35.2)	1805 (36.1)	1863 (38.5)	2210 (39)	

OBS: Oxidative balance score, eGFR: Estimated glomerular filtration rate.

between eGFR and OBS was validated using the restricted cubic spline (RCS) regression method.

3. Results

3.1. Baseline characteristics

The demographic characteristics of the study population are summarized in Table 2. Among the 20,285 individuals included in this study, 10,489 were male and 9796 were female. The mean age of participants was 47.6 years. The majority of participants identified as non-Hispanic White (43.6 %), with individuals in the highest OBS quartile more likely to belong to this demographic compared to those in the lowest OBS quartile. Participants in the highest OBS quartile exhibited higher educational attainment and lower rates of comorbidities, including diabetes, hypertension, kidney stone, renal failure and cardiovascular diseases.The majority of participants had serum estimated glomerular filtration rate (eGFR) levels exceeding 60 mL/min/1.73 m^2, with a mean eGFR level of 83.1 mL/min/1.73 m^2.

3.2. Associations between oxidative balance score and eGFR

The correlation between OBS and eGFR was analyzed using multivariate linear regression, as shown in Table 3. When OBS was treated as a continuous variable, the results indicated a statistically positive correlation between OBS scores and eGFR levels in the crude model (β = 0.15, 95%CI: 0.11–0.20, $P < 0.001$). Specifically, for each unit increase in the OBS score, there was a corresponding increase in eGFR level of 0.15 mL/min/1.73 m^2. After adjusting for all covariates (age, gender, race, marital status, educational level, poverty income ratioa, diabetes, hypertension, kidney stone, renal failure and cardiovascular diseases), a significant postivite correlation was still observed ($P < 0.001$). This association continued to exhibit statistical significance the categorization of OBS score quartiles. The eGFR levels in the highest OBS score quartile were significantly higher than those in the lowest quartile (Model 2, β = 1.61, 95 % CI: 0.95–2.28, $P < 0.001$).

3.3. Subgroup analysis and RCS analysis

Stratified analyses were conducted by sex (Table 4) to account for its effect of sex on eGFR levels. The results indicated that eGFR levels were significantly and postively correlated with OBS scores in both male and female groups, however, males exhibited greater benefits from OBS than females in the crude model as well as in Models 1 and 2 (Crude model, Male, β = 0.22, 95 % CI: 0.16–0.28, $P < 0.001$; Female, β = 0.08, 95 % CI: 0.03, 0.13, P = 0.001). Quartile 2, 3, and 4 exhibited significant differences in males compared to the Quartile 1 group ($P < 0.05$). The multivariate adjusted spline curves illustrating the association between the oxidative stress homeostasis index and serum eGFR levels are depicted in Fig. 2. In the crude model, OBS demonstrated a significant overall relationship with eGFR in both males and females (P for overall <0.001). Notably, a nonlinear relationship between OBS and eGFR was observed in overall (Crude model, P for nonlinear = 0.021) and in females (Crude model, P for nonlinear = 0.022). However, after adjusting for covariates, there was a significant nonlinear relationship between OBS and eGFR only in males (Model 2, P for nonlinear = 0.024).

4. Discussion

This study employed data derived from the National Health and Nutrition Examination Survey (NHANES) spanning the years 2007–2018 to investigate the association between the oxidative balance index (OBS) and the estimated glomerular filtration rate (eGFR). The findings indicated a significant positive correlation between OBS and eGFR levels, specifically, for each unit increase in OBS, there was a corresponding increase in eGFR of 0.15 mL/min/1.73 m^2. These findings offer scientific support for the crucial role of antioxidant-rich diet and a healthy lifestyle in the prevention of kidney disease. The study suggests that augmenting antioxidant intake through dietary and lifestyle modifications may positively influence the prevention and delay of kidney disease progression.

Our findings align with existing literature that indicates an association between oxidative stress and chronic kidney disease (CKD). Previous studies have established a significant negative correlation between oxidative stress (OBS) markers and lower glomerular filtration rate (GFR) in diabetic patients, however, the potential impact of gender differences on these results was not adequately

Table 3
The relationship between oxidative balance score and eGFR.

OBS	Total No.			Model 1		Model 2	
		crude.β (95%CI)	*P* value	adj.model 1, β (95%CI)	adj. *P* value	adj.model 2, β (95%CI)	adj. *P* value
Continuous	20285	0.15 (0.11–0.20)	<0.001	0.19 (0.16–0.23)	<0.001	0.09 (0.06–0.12)	<0.001
Quartile 1	4775	Ref		Ref		Ref	
Quartile 2	5000	1.03 (0.13–1.94)	0.025	1.46 (0.56–1.66)	<0.001	0.53 (−0.15–1.21)	0.0125
Quartile 3	4841	2.22 (1.31–3.13)	<0.001	2.47 (1.70–3.23)	<0.001	1.07 (0.39–1.76)	0.002
Quartile 4	5669	3.05 (2.17–3.92)	<0.001	3.75 (3.01–4.49)	<0.001	1.61 (0.95–2.28)	<0.001

Model 1 adjusted for demographic information (age, gender, race, educational level, poverty income ratioa, marital status).
Model 2 further adjusted for health information (diabetes, hypertension, cardiovascular diseases).

Table 4
Association of OBS with eGFR by gender.

OBS	Continuous		Quartile 1	Quartile 2		Quartile 3		Quartile 4	
	β (95 % CI)	*P* value		β (95 % CI)	*P* value	β (95 % CI)	*P* value	β (95 % CI)	*P* value
crude									
Male	0.22 (0.16–0.28)	<0.001	Ref	1.39 (0.19–2.59)	0.024	3.10 (1.90–4.31)	<0.001	4.09 (2.92–5.26)	<0.001
Female	0.08 (0.03–0.13)	0.001	Ref	0.27 (–0.70–1.25)	0.584	0.15 (–0.85–1.14)	0.774	1.84 (0.90–2.78)	<0.001
adj.model 1									
Male	0.12 (0.07–0.16)	<0.001	Ref	1.78 (0.92–2.65)	<0.001	2.38 (1.51–3.25)	<0.001	2.28 (1.44–3.13)	<0.001
Female	0.11 (0.07–0.16)	<0.001	Ref	0.75 (–0.18–1.68)	0.114	0.77 (-0.19–1.72)	0.115	2.42 (1.51–3.33)	<0.001
adj.model 2									
Male	0.09 (0.05–0.13)	<0.001	Ref	1.44 (0.61–2.28)	<0.001	2.03 (1.19–2.87)	<0.001	1.78 (0.96–2.60)	<0.001
Female	0.02 (−0.02–0.06)	0.293	Ref	−0.04 (–0.88–0.79)	0.922	−0.04 (–1.26–0.45)	0.355	0.72 (–0.10–1.53)	0.087

Model 1 adjusted for demographic information (age, gender, race, educational level, poverty income ratioa, marital status).
Model 2 further adjusted for health information (diabetes, hypertension, cardiovascular diseases).

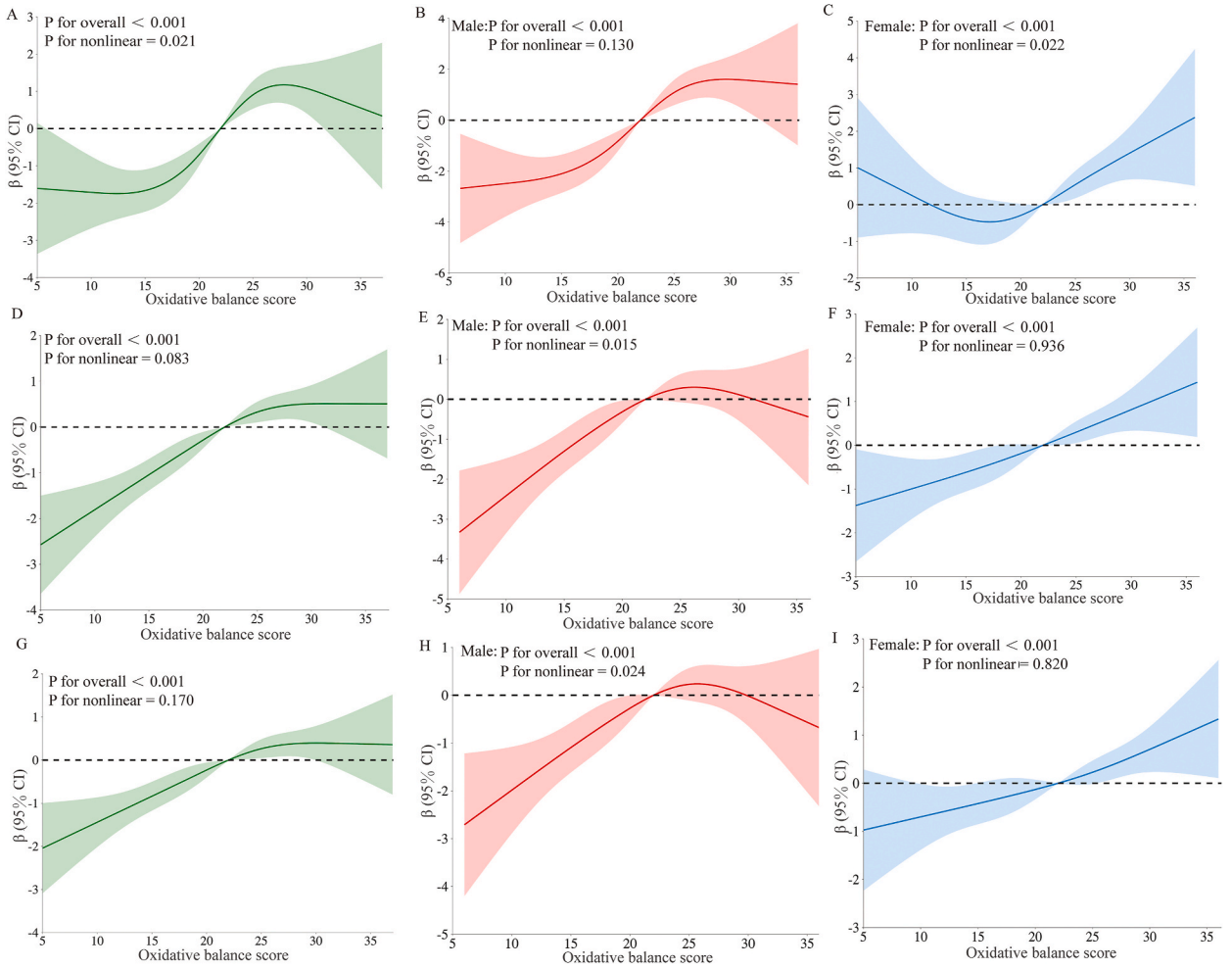

Fig. 2. Analysis of Restricted Cubic Spline Regression. eGFR and OBS were analyzed using crude RCS curves in the overall population (A), males (B), and females (C), without adjusting for covariates. In Model 1, eGFR and OBS were analyzed using RCS curves in the overall population (D), males (E), and females (F). In Model 2, eGFR and OBS were analyzed using RCS curves in the overall population (G), males (H), and females (I). Model 1 adjusted for demographic information (age, gender, race, educational level, poverty income ratioa, marital status); Model 2 further adjusted for health information (diabetes, hypertension, cardiovascular diseases). Abbreviations: eGFR: estimated glomerular filtration rate; OBS: oxidative balance score.

addressed. The components of OBS such as dietary fiber, carotenoids, vitamin C, vitamin E, and others have been extensively documented to play an important role in maintaining kidney health. Specifically, a prospective study indicated that each 5 g increase in daily total dietary fiber intake is associated with an 11 % reduction in the risk of chronic kidney disease (CKD) [22]. A dietary pattern abundant in plant foods, characterized by high fiber content, significantly reduces the incidence of albuminuria and may positively influence eGFR. Dietary fiber undergoes fermentation in the gut, resulting in the production of short-chain fatty acids (SCFAs), a process that promotes the growth of beneficial gut bacteria, mitigates gut-derived uremic toxins, inflammation, and oxidative stress, and enhances metabolic status [23–26]. Furthermore, low fiber intake correlates with elevated serum levels of inflammatory biomarkers, including C-reactive protein (CRP), interleukin 6 (IL-6), and tumor necrosis factor alpha receptor 2 (TNF-a R2) [27–29], which not only elevate the risk of cardiovascular mortality, but may also contribute to the development and progression of CKD. Conversely, high-fiber diets diminish the risk of cardiovascular disease and are linked to reduced inflammation and all-cause mortality among patients with CKD. These findings underscore the critical role of dietary fiber in preserving kidney health. Carvalho CM et al. demonstrated that individuals exhibiting the highest serum levels of carotenoids experienced a markedly lower risk of rapid renal function decline in comparison to those in the lowest quartile, a significant positive correlation was identified between carotenoid levels and eGFR in the elderly population [30]. Furthermore, research conducted by Di XP et al. indicated that dietary riboflavin intake was inversely associated with the incidence of kidney stone disease (KSD) [31]. Niacin, recognized as an a vital antioxidant dietary component in the diet, has been demonstrated in multiple studies to exert a potentially beneficial effect on the preservation of kidney health. Niacin has been shown to significantly reduce serum phosphorus levels, thereby potentially positively influencing kidney health. This finding holds particular significance for patients with CKD, who frequently encounter difficulties in managing serum phosphorus levels. Niacin has the capacity to attenuate the decline in GFR by improving lipid profiles and mitigating inflammation [32,33]. Calcium levels exert a significant influence on the GFR, with elevated calcium levels correlating with a decelerated decline in eGFR during advanced CKD stages. Calcium supplementation may lead to a modest increase in serum creatinine levels, particularly among participants with a low eGFR [34,35]. Vitamin C is a potent antioxidant that is essential for maintaining renal health. Vitamin C intake has been found to be positively correlated with GFR, especially in those with low magnesium intake [36]. Elevated serum vitamin C levels are associated with a reduced risk of developing low GFR and CKD [37]. However, high doses of vitamin C intake may lead to acute oxalate nephropathy, particularly in patients with pre-existing renal conditions; therefore, caution is warranted when considering vitamin C supplementation [38]. Vitamin B6 (pyridoxine) functions as a coenzyme for various enzymes and is involved in more than 100 enzymatic reactions, including amino acid metabolism and neurotransmitter synthesis. Research indicates that vitamin B6 deficiency may result in the deposition of oxalate crystals in the body, subsequently increasing the likelihood of kidney stone formation [39]. Magnesium has demonstrated potential anti-urolithic properties in vitro studies by inhibiting the formation of calcium oxalate crystals in urine, binding free oxalate, and enhancing its solubility [40,41]. Vitamin E, a fat-soluble antioxidant, has garnered significant attention for its role in renal protection. Relevant studies indicate a negative correlation between increased intake of vitamin E and diminished renal function, as well as low GFR in women [42]. These findings suggest that vitamin E may confer a protective effect on renal health by attenuating oxidative stress and inflammatory responses [43,44]. However, in men, this protective effect does not seem to be significant, indicating that gender may play a crucial role in modulating the effects of vitamin E.

The relationship between alcohol consumption and eGFR is complex and exhibits dose-dependent characteristics. Moderate alcohol consumption appears to confer benefits to renal function; however, excessive alcohol intake may result in a decline in renal function. Moderate alcohol consumption is associated with a slight elevation in eGFR [45]. Conversely, a study conducted by Kimura Y indicated that high daily alcohol intake is associated with a significant reduction in eGFR [46]. These findings underscore the significance of moderate alcohol consumption and suggest that excessive alcohol intake may adversely affect renal health. Smoking is recognized as an independent risk factor for CKD. Cotinine, a metabolite of nicotine, has been demonstrated to adversely influence GFR. Serum cotinine levels have been observed to be inversely related to glomerular filtration rate, indicating that smoking may exacerbate renal impairment [47,48]. A study conducted by La Scola C et al. demonstrated a gradual decline in eGFR levels across patients ranging from underweight to obese classifications [49]. Numerous studies have indicated that an increase in body mass index (BMI) is positively correlated with the risk of KSD and lower eGFR [50,51].

The measurement of a singular element may prove inadequate in comprehensively elucidating its antioxidant role within the organism. As an indicator of the overall oxidative-antioxidant balance, the OBS may more accurately represent the organism's oxidative stress status. The present study demonstrated a correlation between the OBS and eGFR, attributed to the large sample size and the diverse multi-ethnic population data utilized. Nonetheless, certain limitations are associated with this study. Firstly, the cross-sectional design employing the NHANES dataset precluded the establishment of a definitive causal relationship between OBS and eGFR. Secondly, data regarding the intake of dietary fiber, carotenoids, and vitamins were obtained through a two-day, 24-h retrospective method, potentially introducing recall bias. Thirdly, the threshold effect of antioxidants was not addressed in this study; certain antioxidants may demonstrate pro-oxidant activity at elevated doses or under specific conditions, such as those observed with copper and carotenoids. In summary, additional experimental studies are warranted to elucidate the specific mechanisms underlying the interactions between antioxidant components and kidney disease. Furthermore, the gender differences identified in the study indicate that eGFR levels in men are more sensitive to fluctuations in OBS, potentially attributable to physiological, metabolic, and hormonal differences between genders. These distinctions may significantly influence the generation of oxidative stress and the mechanisms through which antioxidant substances exert their effects. Future investigations should further examine how gender influences the relationship between oxidative stress and renal function.

CRediT authorship contribution statement

Mingda Wu: Methodology, Data curation. **Cuiting Dong:** Methodology, Investigation, Formal analysis. **Zhen Yang:** Methodology, Investigation, Data curation. **Yongfu Song:** Software, Methodology. **Chenkai Xu:** Formal analysis, Data curation. **Shuang Ma:** Writing – original draft, Formal analysis. **Yuejiao Lan:** Supervision, Investigation, Funding acquisition. **Xiaodan Lu:** Supervision, Resources, Funding acquisition.

Ethics approval and consent to participate

This cross-sectional study included subjects from the consecutive nationally representative NHANES conducted between 2007 and 2018. The NHANES protocol was approved by the Ethics Review Board of the National Center for Health Statistics. The NHANES study protocol adhered to the principles of the Declaration of Helsinki, and obtained written informed consent from all participants. Data used in this study are de-identified and publicly available (https://www.cdc.gov/nchs/nhanes/index.htm).

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Declaration of competing interest

All authors disclosed no relevant relationships.

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