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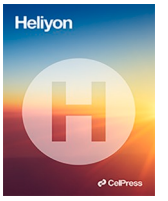

Research article

Association between dietary fiber intake and diabetic nephropathy among adult diabetes mellitus in the United States: A cross-sectional study

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ABSTRACT

Objective: There has been some evidence that dietary fiber may be associated with diabetic nephropathy (DN), but the relationship is still unclear. The purpose of this study was to examine the association between dietary fiber intake and DN.

Methods: This cross-sectional study used National Health and Nutrition Examination Survey (NHANES) data collected between 2007 and 2020. Weighted multivariate logistic regression was used to examine the relation between dietary fiber intake and DN. In addition, fitted smoothed curves were used to explore potential non-linear relationships. If non-linearity was observed, inflection points were further calculated by a recursive algorithm.

Results: The study finally included 5964 subjects ≥20 years of age. The mean age was 60.8 ± 13.4 years with males (52.4 %), and non-Hispanic Whites (62.4 %), and the weighted prevalence of DN was 36.7 %. Dietary fiber was negatively associated with the risk of DN after controlling for all confounding variables (OR = 0.89, 95%CI: 0.80, 0.99). Smoothed curve fit plots of the dose relationship showed that dietary fiber intake was linearly related to DN, whereas males (inflection point of 8.0 g/d) and non-Hispanic Blacks (inflection point of 14.9 g/d) followed a non-linear inverted U-shaped curve relationship. In United States adults aged 20 and older, dietary fiber intake may be associated with a reduced risk of DN.

Conclusion: Appropriate increases in dietary fiber intake may offer potential benefits for DN. In conclusion, it appears that increasing dietary fiber intake may be one of the most effective strategies for the prevention and management of DN.

1. Introduction

In 2021, nearly 540 million people had diabetes mellitus (DM) globally, and by 2045, this number is expected to reach 780 million [1]. One of DM's major microvascular complications is diabetic nephropathy (DN). The main manifestations are decreased glomerular filtration rate (GFR), increased urinary albumin, and hypertension, which ultimately leads to end-stage renal disease (ESRD). This is the main cause of DM morbidity [2,3]. It is worth noting that approximately 30–40 % of DM in the United States (US) progresses to DN [4]. Many factors have been reported to contribute to the progression of DN, such as hypertension [5], obesity [6], and hyperglycemia

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[2]. Dietary habits may be one of the most favorable factors for DN [7,8]. However, as it stands, there are still areas of dietary management that are not fully addressed in clinical practice guidelines, and thus dietary interventions may be a future trend in the prevention and treatment of DN [7,9]. Therefore, it is necessary to learn more about dietary factors that may help prevent and manage DN.

In recent years, dietary fiber consumption has been increasingly studied for its health benefits. Dietary fiber is a plant polysaccharide that cannot be hydrolyzed and absorbed by human digestive enzymes, also known as non-absorbed plant carbohydrates. Nevertheless, intestinal flora can ferment it into short-chain fatty acids [10]. It has been reported that fiber intake can reduce the risk of cardiovascular disease, type 2 diabetes mellitus (T2DM), and cancer when consumed in moderation [11,12]. Increasing fiber intake in patients with chronic kidney disease reduces all-cause mortality, according to a recent prospective study [13]. These benefits may result from the important mechanisms of dietary fiber on intestinal motility, insulin sensitivity, glycemic control, chronic inflammation, and gut microbiology [14,15]. However, it is not clear if dietary fiber has benefits on DN.

As far as we know, large-sample epidemiological studies on dietary fiber and DN in the US have been very limited in the past decades. Thus, further research on the beneficial effects of dietary fiber on DN is necessary. We evaluated fiber intake and DN risk for the first time in this study. The study used large-sample real-world data from the National Health and Nutrition Examination Survey (NHANES) (2007–2020). Our research will provide ideas for subsequent basic clinical research and give new insights and evidence for nutritional guidelines and health policy.

2. Materials and methods

2.1. Study population

In this study, data were obtained from the NHANES database, an annual survey conducted by the Centers for Disease Control and Prevention in the US, which mainly consisted of questionnaires, nutritional information, physical examinations, and laboratory findings. An unbiased, stratified, multistage probability sampling was used to represent the non-institutionalized civilian population of the US over a period of two years [16]. Participants in the NHANES study provided written informed consent to the Ethics Review Board of the National Center for Health Statistics (NCHS). Data were selected from NHANES (2007–2020), which recruited 66,148 participants. Inclusion exclusion (Fig. 1): excluded were those less than 20 years of age, those not having DM, missing data on dietary fiber intake, missing data on urinary albumin creatinine ratio, missing data on glomerular filtration rate, and pregnant. The final 5964

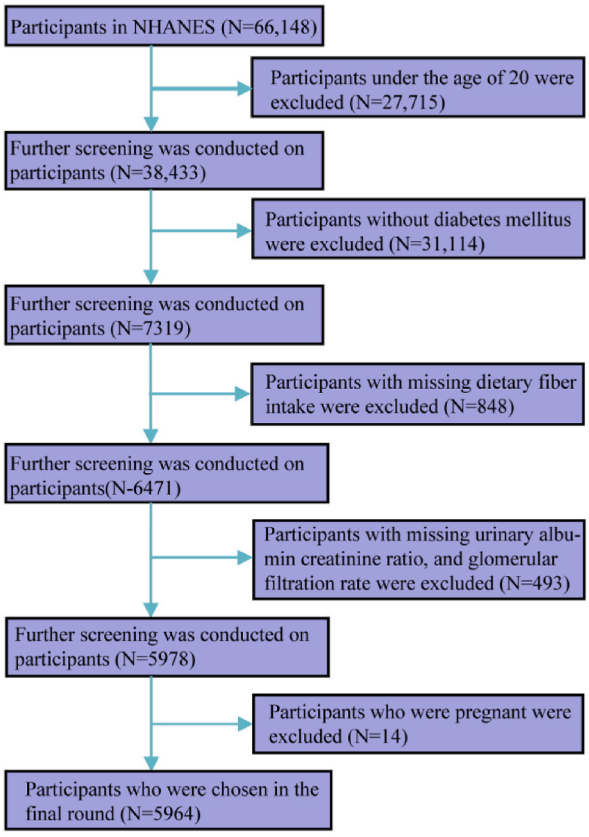

Fig. 1. Diagram showing how the study population is selected.

DM participants took part in the study.

2.2. Exposure variable

Food beverages and dietary supplements consumed during two 24-h dietary periods (midnight to midnight) were used to measure the intake of dietary fiber. The energy, nutrition, and other food components in food and beverages were also estimated [17]. In the Mobile Examination Center (MEC), the first dietary recall interview was conducted in person by trained professionals, and the second interview was conducted over the phone three to ten days later by trained professionals. If the participant completed two 24-h recalls, the average was used, and if only one was completed, the first 24-h recall data was used. The US Department of Agriculture was used to calculate the nutritional values of all foods, beverages, and supplements.

2.3. Outcome variable

NHANES self-report questionnaire and the American Diabetes Association (ADA) diagnostic criteria were used to diagnose participants with diabetes [18]. An individual must have glycated hemoglobin of at least 6.5 %, fasting blood glucose (FPG) of 126 mg/dL, 2-h plasma glucose of at least 200 mg/dL, and be taking an insulin or hypoglycemic medication currently. In the present study, all DM participants were included in the study. The outcome variable was whether or not they had DN. The participants were defined as having DN when the urinary albumin to creatinine ratio (UACR) was $\geq$ (30 mg/g) or when the estimated glomerular filtration rate (eGFR) was $<$60 mL/min/1.73 m^2. Otherwise, they were defined as non-DN [19,20]. Documents describing data collection and laboratory testing methods are publicly available and free of charge on the NHANES website.

2.4. Covariates

Previous studies helped us determine the covariates [21–23]. Population characteristics: age, gender, race, education, and poverty income ratio. Lifestyle factors: smoking behavior, drinking behavior, physical activity, dietary fiber intake, energy intake, carbohydrate intake, and fiber supplement. Biochemical examination: alanine aminotransferase (ALT), aspartate aminotransferase (AST), blood urea nitrogen (BUN), serum creatinine (SCR), total bilirubin (TBIL), total cholesterol (TC), triglyceride (TG), serum uric acid (SUA), HBA1C, and high-density lipoprotein cholesterol (HDL-C). Medical examination data: body mass index (BMI), and waist circumference (WC). Disease diagnosis: high blood pressure (HBP), hyperlipidemia, and cardiovascular disease (CVD). Free access to the NHANES data was provided on the website. HBP was defined as having HBP as diagnosed by a doctor or currently taking prescription drugs for HBP, and systolic blood pressure (SBP) $\geq$ 130 mmHg or diastolic blood pressure (DBP) $\geq$ 80 mmHg [24]. A BMI group is designated as underweight or normal weight (under 25.0 kg/m^2), overweight (between 25.0 and 29.9 kg/m^2), and obese (over 29.9 kg/m^2). Hyperlipidemia was defined as having hyperlipidemia diagnosed by a doctor or TC $\geq$ 240 mg/dL, TG $\geq$ 200 mg/dL, HDL-C $<$ 40 mg/dL, low-density lipoprotein-cholesterol (LDL-C) $\geq$ 160 mg/dL [22]. Among the CVDs identified were congestive heart failure (CHF), coronary heart disease (CHD), angina, heart attack, and stroke.

2.5. Statistical analyses

Given the representative nature of the study results, we performed weighting and variance estimation as recommended by the Centers for Disease Control and Prevention guidelines. R (version 4.2.0) and EmpowerStats (www.empowerstats.com; X&Y Solutions, Inc., Boston, MA, USA) were used for statistical analysis. Considering that participants' dietary fiber intake was skewed, we transformed the data by log2 to conform to a normal distribution and grouped them into four groups (Q1, Q2, Q3, Q4). For continuous variables, mean +SD or median (IQR, skewed distribution) were used, and Kruskal-Wallis tests or weighted linear regression models were used for comparisons between the groups. To examine the association between dietary fiber intake and DN, we implemented weighted univariate and multivariate logistic regression, following the guidelines recommended by Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) [25]. This observational study developed 3 models: Model 1 (unadjusted); Model 2 (adjusted for age, gender, race, education, and poverty income ratio); and Model 3 (adjusted for all covariates). Trend analysis was also conducted using the median dietary fiber intake quartiles as a continuous variable. In addition, we stratified the analysis by gender and race. A smoothed curve fitting algorithm and generalized additive modeling were used to examine the non-linear relationship between dietary fiber intake and DN. Recursive algorithms were used to calculate the inflection point of nonlinear relationships. Based on the log-likelihood ratio test, construct a two-segment linear model on either side of the inflection point. If $p > 0.05$, the log-likelihood ratio test indicates a linear relationship, otherwise, a non-linear relationship.

3. Results

3.1. Typical characteristics of the population

The data were selected from NHANES (2007–2020), which ultimately included 5964 subjects aged 20–85 years after passing a series of nadir criteria (Fig. 1). The mean age was 60.8 $\pm$ 13.4 years for males (52.4 %) and females (47.6 %). There were 62.4 % non-Hispanic Whites, 13.7 % non-Hispanic Blacks, 9.9 % Mexican Americans, and 14.1 % other races. Weighted population characteristics according to the presence or absence of DN (Table 1) revealed significant differences between the two groups for age, education,

Table 1
Characteristics of the population describing the occurrence of diabetic nephropathy.

Variable Features	Total	Is there diabetic nephropathy?		*p*-Value
		NO	YES	
	n = 5964	n = 3607	n = 2357	
Population characteristics				
Age, mean ± SD, years	60.8 ± 13.4	58.0 ± 13.2	65.1 ± 12.6	<0.001
Gender, n (%), (95%CI)				0.277
Male	52.4 (50.6,54.3)	53.3 (50.8,55.8)	51.0 (48.0,54.0)	
Female	47.6 (45.7,49.4)	46.7 (44.2,49.2)	49.0 (46.0,52.0)	
Race, n (%), (95%CI)				0.081
Mexican American	9.9 (7.9,12.2)	10.3 (8.2,12.7)	9.1 (7.2,11.6)	
Non-Hispanic White	62.4 (58.7,65.9)	61.2 (57.3,65.0)	64.3 (60.4,68.1)	
Non-Hispanic Black	13.7 (11.8,15.9)	13.9 (11.8,16.2)	13.4 (11.4,15.7)	
Other race	14.1 (12.6,15.7)	14.6 (12.9,16.5)	13.2 (11.4,15.1)	
Education, n (%), (95%CI)				0.001
<High school	22.7 (21.0,24.4)	21.1 (19.1,23.3)	25.3 (23.3,27.3)	
High school	25.7 (23.9,27.7)	24.7 (22.2,27.4)	27.5 (25.0,30.1)	
>High school	51.6 (49.5,53.8)	54.2 (51.2,57.1)	47.3 (44.4,50.2)	
Poverty income ratio, n (%), (95%CI)				<0.001
<1.3	23.3 (21.8,25.0)	21.4 (19.7,23.2)	26.7 (24.5,28.9)	
1.3–3.5	36.5 (34.5,38.5)	35.0 (32.8,37.3)	39.0 (36.3,41.8)	
>3.5	33.0 (30.7,35.3)	36.1 (33.4,39.0)	27.5 (24.4,30.9)	
Missing	7.2 (6.3,8.2)	7.5 (6.5,8.7)	6.8 (5.6,8.1)	
Lifestyle factors				
Smoking behavior, n (%), (95%CI)				0.011
Never smoked	49.1 (47.2,51.1)	50.4 (47.7,53.1)	46.9 (43.9,50.0)	
Former smoker	35.1 (33.3,36.9)	33.0 (30.4,35.6)	38.7 (35.9,41.6)	
Current smoker	15.8 (14.6,17.1)	16.7 (15.0,18.5)	14.4 (12.5,16.4)	
Drinking behavior, n (%), (95%CI)				<0.001
Never drank	12.2 (11.0,13.4)	11.2 (9.7,12.8)	13.9 (12.2,15.9)	
Moderate drinker	37.9 (35.7,40.0)	38.4 (35.6,41.3)	36.9 (34.5,39.4)	
Heavy drinker	31.4 (29.3,33.6)	33.9 (31.0,36.8)	27.2 (24.5,30.1)	
Missing	18.5 (17.2,19.9)	16.6 (15.0,18.3)	21.9 (19.8,24.3)	
Physical activity, n (%), (95%CI)				<0.001
vigorous activity	41.5 (39.5,43.4)	37.4 (34.8,40.1)	48.5 (46.0,51.0)	
moderate activity	34.9 (33.0,36.9)	36.2 (33.8,38.8)	32.8 (30.1,35.5)	
light activity	23.6 (21.9,25.4)	26.4 (24.3,28.6)	18.8 (16.6,21.1)	
Dietary fiber intake, median (IQR), g/d	14.4 (10.2–20.6)	15.2 (10.5–21.6)	13.6 (9.6–18.9)	<0.001
Energy intake, mean, mean ± SD, kcal/d	1849.7 ± 782.3	1896.0 ± 788.7	1778.9 ± 767.2	<0.001
Carbohydrate intake, mean ± SD, g/d	219.0 ± 97.0	224.8 ± 97.9	210.1 ± 94.9	<0.001
Dietary fiber supplement, n (%), (95%CI)	3.5 (2.8,4.3)	3.8 (2.9,5.0)	2.9 (2.0,4.1)	0.245
Biochemical examination				
ALT, median (IQR), U/L	21.0 (16.0–30.0)	22.0 (17.0–31.0)	20.0 (15.0–27.0)	0.097
AST, median (IQR), U/L	22.0 (18.0–28.0)	23.0 (19.0–28.0)	22.0 (18.0–28.0)	0.963
BUN, median (IQR), mg/dL	15.0 (11.0–19.0)	13.0 (11.0–16.0)	18.0 (13.0–24.0)	<0.001
SCR, median (IQR), mg/dL	0.9 (0.7–1.1)	0.8 (0.7–0.9)	1.1 (0.8–1.4)	<0.001
TBIL, mean ± SD, mg/dL	0.6 ± 0.3	0.6 ± 0.3	0.6 ± 0.3	0.262
TG, median (IQR), mg/dL	149.0 (102.0–221.0)	145.0 (99.0–215.0)	153.0 (105.0–232.0)	<0.001
TC, mean ± SD, mg/dL	185.1 ± 46.8	186.9 ± 45.9	182.2 ± 48.1	0.027
HDL-C, mean ± SD, mg/dL	48.1 ± 14.7	48.4 ± 14.3	47.7 ± 15.2	0.572
SUA, mean ± SD, mg/dL	5.8 ± 1.6	5.5 ± 1.4	6.2 ± 1.8	<0.001
HBA1C, mean ± SD, %	7.3 ± 1.7	7.1 ± 1.6	7.5 ± 1.9	<0.001
ACR, median (IQR), mg/g	12.6 (6.8–39.4)	8.6 (5.7–13.9)	59.0 (26.9–174.7)	<0.001
eGFR, mean ± SD, mL/min/1.73 m2	83.7 ± 28.8	92.8 ± 22.4	69.7 ± 31.6	<0.001
Medical examination data				
BMI, n (%), (95%CI)				<0.001
<25.0 kg/m^2	11.3 (10.2,12.4)	11.0 (9.6,12.6)	11.7 (10.1,13.6)	
25.0–29.9 kg/m^2	25.9 (24.5,27.3)	27.1 (25.2,29.2)	23.7 (21.8,25.8)	
>29.9 kg/m^2	61.7 (59.8,63.6)	61.2 (58.7,63.7)	62.6 (60.1,65.1)	
Missing	1.1 (0.8,1.5)	0.6 (0.4,1.0)	1.9 (1.4,2.8)	
WC, mean ± SD, cm	109.3 ± 15.6	108.8 ± 15.8	110.0 ± 15.2	0.062
SBP, mean ± SD, mmHg	131.0 ± 19.5	127.9 ± 17.2	135.7 ± 21.8	<0.001
DBP, mean ± SD, mmHg	69.9 ± 14.3	70.8 ± 13.1	68.5 ± 15.7	<0.001
Disease diagnosis				
HBP, n (%), (95%CI)	73.0 (71.1,74.7)	67.6 (65.2,70.0)	82.2 (80.1,84.2)	<0.001
Hyperlipidemia, n (%), (95%CI)	70.3 (68.7,71.9)	67.7 (65.6,69.8)	74.8 (72.5,77.0)	<0.001
CHF, n (%), (95%CI)	7.8 (6.8,8.9)	4.2 (3.3,5.3)	13.9 (11.9,16.1)	<0.001
CHD, n (%), (95%CI)	10.7 (9.5,12.0)	8.1 (6.7,9.7)	15.2 (13.4,17.3)	<0.001
Angina, n (%), (95%CI)	6.9 (6.1,7.8)	5.7 (4.5,7.1)	9.0 (7.5,10.7)	0.005

(*continued on next page*)

Table 1 (*continued*)

Variable Features	Total	Is there diabetic nephropathy?		*p*-Value
		NO	YES	
	n = 5964	n = 3607	n = 2357	
Heart attack, n (%), (95%CI)	9.9 (8.9,11.0)	7.7 (6.6,9.0)	13.7 (11.9,15.8)	<0.001
Stroke, n (%), (95%CI)	7.4 (6.5,8.3)	4.8 (3.9,5.8)	11.8 (10.0,13.9)	<0.001
CVD, n (%), (95%CI)	21.3 (19.9,22.9)	16.0 (14.3,17.9)	30.4 (27.7,33.4)	<0.001

poverty income ratio, smoking behavior, drinking behavior, physical activity, energy intake, carbohydrate intake, dietary fiber intake, BMI, SBP, DBP, HBP, hyperlipidemia, CHF, CHD, angina, heart attack, stroke, CVD, BUN, SCR, TG, TC, SUA, HBA1C, ACR and eGFR. Gender, race, fiber supplement, ALT, AST, TBIL, WC, and HDL-C did not differ between the two groups.

3.2. DN correlated univariate analysis

A weighted one-way analysis of variance (Table 2) showed that dietary fiber intake, age, education, poverty income ratio, energy intake, carbohydrate intake, SBP, DBP, HBP, smoking behavior, drinking behavior, physical activity, BUN, SCR, TC, TG, SUA, HBA1C, hyperlipidemia, and CVD were significantly correlated to DN. However, gender, race, fiber supplement, WC, BMI, ALT, AST, TBIL, and HDL-C were not statistically significant with DN. Having HBP was associated with a higher risk compared to not having HBP (OR = 2.22, 95%CI: 1.88, 2.63). Having hyperlipidemia was associated with a higher risk compared to not having hyperlipidemia (OR = 1.42, 95%CI: 1.22, 1.65). Having CVD was associated with a higher risk compared to not having CVD (OR = 2.29, 95%CI: 1.89, 2.77). In addition, dietary fiber intake, and DBP, were negatively associated with the risk of developing DN, playing as protective factors. On the contrary, age, energy intake, carbohydrate intake, SBP, BUN, SCR, TC, TG, SUA, and HBA1C were positively associated with the risk of developing DN, acting as risk factors.

3.3. Multiple logistic regression analysis of dietary fiber intake and DN

To obtain the relationship between dietary fiber and DN, we used three models to analyze the effect values (Table 3). Unadjusted modeling results indicated (Model 1) that dietary fiber was negatively associated with the risk of DN (OR = 0.78, 95%CI: 0.72, 0.84). This indicated that for every 1 unit of dietary fiber (log2 transform), there was a 22 % reduction in the risk of developing DN. The results of the micro-adjustment model showed (Model 2) that dietary fiber was negatively associated with the risk of DN (OR = 0.77, 95%CI: 0.72, 0.83). The equivalent of each 1-unit in dietary fiber (log2 transform) led to a 23 % reduction in the risk of developing DN. The results of the fully adjusted model showed (Model 3) that dietary fiber was negatively associated with the risk of DN (OR = 0.89, 95%CI: 0.80, 0.99). The equivalent of each 1 unit in dietary fiber (log2 transform) resulted in an 11 % reduction in the risk of developing DN. To verify the stability of the results, dietary fiber was grouped into quartiles (Q1, Q2, Q3, Q4) and validated in three models (Table 3). In Model 1, the risk of DN was negatively correlated in Q3 and Q4 compared to Q1, respectively (OR = 0.75, 95%CI: 0.63, 0.91; OR = 0.56, 95%CI: 0.48, 0.67). In Model 2, the risk of DN was negatively correlated in Q3 and Q4 compared to Q1, respectively (OR = 0.71, 95%CI: 0.59, 0.85; OR = 0.56, 95%CI: 0.47, 0.67). In Model 3, the risk of DN was negatively correlated in Q4 compared to Q1. Overall, the risk of developing DN tended to decrease with increasing dietary fiber intake (Q1-Q4) in all 3 models, and the test for trend was consistently significant (model 1, p for trend <0.001; model 2, p for trend <0.001; model 3, p for trend = 0.003), with results consistent with those for continuous variables. We plotted a smoothed curve fit (p for non-linearity = 0.064) through Model 3 to better see if there was a non-linear relationship between dietary fiber intake and DN (Fig. 2).

3.4. Analyzing the correlation between dietary fiber and DN in subgroups

We further conducted a subgroup analysis stratified by gender and race (Table 4). In the study, females and males exhibited negative correlations (OR = 0.87, 95%CI: 0.74, 1.01; OR = 0.91, 95%CI: 0.78, 1.06), but the results were not significant. Non-Hispanic White, non-Hispanic Black, and other race were all negatively correlated with dietary fiber intake (OR = 0.88, 95%CI: 0.76, 1.01; OR = 0.94, 95%CI: 0.79, 1.12; OR = 0.77, 95%CI: 0.60, 0.99), and only other race has a significant correlation. Mexican Americans were positively correlated (OR = 1.09, 95%CI: 0.85, 1.40). In addition, we drew smooth curves for gender and race-stratified subgroups to further observe non-linear relationships (Fig. 3, Fig. 4). We found a non-linear inverted U-shaped relationship among male and non-Hispanic blacks (p for log-likelihood ratio tests <0.05). A two-section model was used to calculate the inflection point (Table 5). For males (the inflection point was 8.0 g/d), when the dietary fiber intake was >8.0 g/d, the risk of DN was reduced by 23 % (OR = 0.77, 95%CI: 0.64, 0.91). For non-Hispanic Black (the turning point is 14.9 g/d), when the dietary fiber intake of non-Hispanic Black was >14.9 g/d, the risk of DN was reduced by 44 % (OR = 0.56, 95%CI: 0.35, 0.89).

4. Discussion

An investigation of the relationship between dietary fiber intake and DN was undertaken in this study. Results showed dietary fiber intake is negatively related to DN risk (OR = 0.89, 95%CI: 0.80, 0.99). By increasing dietary fiber by 1 unit, the risk of developing DN

Table 2
Univariate analysis of risk factors for diabetic nephropathy, weighted.

Variable	N	DN	
		OR (95%CI)	*p*-value
Fiber intake (log2 transform)	5964	0.78 (0.72, 0.84)	<0.001
Age	5964	1.05 (1.04, 1.05)	<0.001
Gender			
Male	3126	Ref.	
Female	2838	1.10 (0.93, 1.29)	0.280
Race			
Mexican American	1048	Ref.	
Non-Hispanic White	2121	1.18 (0.99, 1.40)	0.065
Non-Hispanic Black	1495	1.08 (0.90, 1.29)	0.405
Other race	1300	1.01 (0.83, 1.24)	0.924
Education			
<High school	1946	Ref.	
High school	1403	0.93 (0.77, 1.13)	0.456
>High school	2615	0.73 (0.61, 0.87)	0.001
Poverty income ratio			
<1.31	1910	Ref.	
1.31–3.50	2147	0.89 (0.79, 1.01)	0.070
>3.50	1334	0.61 (0.50, 0.74)	<0.001
Missing	573	0.72 (0.59, 0.89)	0.003
Fiber supplement			
No	5806	Ref.	
Yes	158	0.76 (0.47, 1.21)	0.249
Energy intake	5964	1.00 (1.00, 1.00)	<0.001
Carbohydrate intake	5964	1.00 (1.00, 1.00)	<0.001
SBP	5964	1.02 (1.02, 1.03)	<0.001
DBP	5964	0.99 (0.98, 0.99)	<0.001
HBP			
No	1497	Ref.	
Yes	4467	2.22 (1.88, 2.63)	<0.001
WC	5964	1.00 (1.00, 1.01)	0.063
BMI			
<25.0 kg/m^2	762	Ref.	
25.0–29.9 kg/m^2	1683	0.82 (0.63, 1.07)	0.146
>29.9 kg/m^2	3441	0.96 (0.76, 1.22)	0.738
Missing	78	2.98 (1.58, 5.61)	0.001
Smoking behavior			
Never smoked	3027	Ref.	
Former smoker	1972	1.26 (1.04, 1.53)	0.020
Current smoker	965	0.92 (0.74, 1.16)	0.492
Drinking behavior			
Never drank	791	Ref.	
Moderate drinker	2078	0.77 (0.62, 0.95)	0.019
Heavy drinker	1729	0.64 (0.50, 0.83)	0.001
Missing	1366	1.06 (0.83, 1.35)	0.641
Physical activity			
Vigorous activity	2745	Ref.	
Moderate activity	1901	0.70 (0.59, 0.83)	<0.001
Light activity	1318	0.55 (0.46, 0.65)	<0.001
ALT	5964	1.00 (0.99, 1.00)	0.397
AST	5964	1.00 (1.00, 1.00)	0.964
BUN	5964	1.14 (1.12, 1.15)	<0.001
SCR	5964	45.54 (32.84, 63.15)	<0.001
TBIL	5964	0.89 (0.73, 1.09)	0.261
TC	5964	1.00 (1.00, 1.00)	0.024
TG	5964	1.00 (1.00, 1.00)	0.032
SUA	5964	1.37 (1.31, 1.43)	<0.001
HBA1C	5964	1.18 (1.14, 1.23)	<0.001
HDL-C	5964	1.00 (0.99, 1.00)	0.589
Hyperlipidemia			
No	1856	Ref.	
Yes	4108	1.42 (1.22, 1.65)	<0.001
CVD			
No	4656	Ref.	
Yes	1308	2.29 (1.89, 2.77)	<0.001

Table 3
The relationship between fiber intake and diabetic nephropathy, weighted.

Exposure variables	Model 1	Model 2	Model 3
	OR(95 % CI)	OR(95 % CI)	OR(95 % CI)
Fiber intake (log2 transform) per 1 mg/dL increase	0.78 (0.72, 0.84)	0.77 (0.72, 0.83)	0.89 (0.80, 0.99)
Fiber intake (log2 transform) (quartiles)			
Q1	Ref.	Ref.	Ref.
Q2	0.93 (0.78, 1.12)	0.89 (0.74, 1.07)	1.02 (0.81, 1.28)
Q3	0.75 (0.63, 0.91)	0.71 (0.59, 0.85)	0.83 (0.66, 1.05)
Q4	0.56 (0.48, 0.67)	0.56 (0.47, 0.67)	0.73 (0.57, 0.93)
P for trend	<0.001	<0.001	0.003

Model 1: unadjusted.
Model 2: adjust for age, gender, race, education, and poverty income ratio.
Model 3: adjust for age, gender, race, education, poverty income ratio, smoking behavior; drinking behavior; physical activity, fiber supplement, energy intake, carbohydrate intake, SBP, DBP, HBP, BMI, WC, ALT, AST, BUN, SCR, TBIL, HBA1C, TG, TC, HDL-C, SUA, hyperlipidemia, CVD.

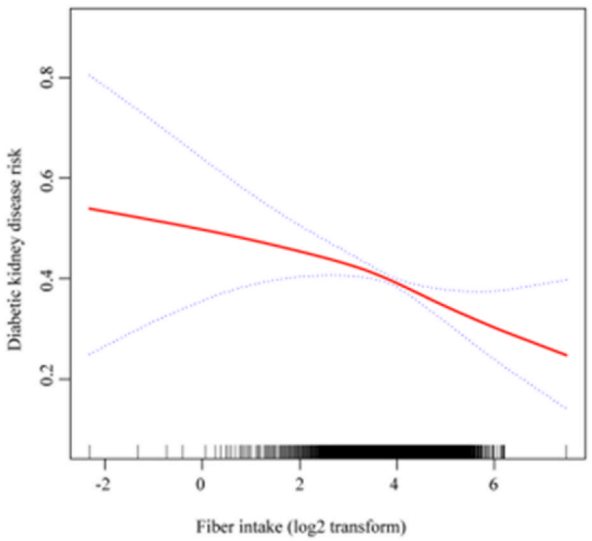

Fig. 2. Relationship between fiber intake and risk of diabetic nephropathy (Model 3). The area between the two blue curves represents the 95 % CI.

Table 4
A weighted study of fiber intake and diabetic nephropathy stratified by race, gender, and high blood pressure.

Exposure variables	Model 1	Model 2	Model 3
	OR(95 % CI)	OR(95 % CI)	OR(95 % CI)
Subgroup analysis stratified by			
Gender			
Male	0.73(0.65, 0.82)	0.73 (0.65, 0.82)	0.87 (0.74, 1.01)
Female	0.83 (0.74, 0.93)	0.81 (0.73, 0.91)	0.91 (0.78, 1.06)
Race			
Mexican American	0.79 (0.68, 0.92)	0.88 (0.74, 1.03)	1.09 (0.85, 1.40)
Non-Hispanic White	0.77 (0.68, 0.86)	0.75 (0.67, 0.84)	0.88 (0.76, 1.01)
Non-Hispanic Black	0.88 (0.76, 1.01)	0.87 (0.75, 1.02)	0.94 (0.79, 1.12)
Other race	0.68 (0.57, 0.80)	0.68 (0.57, 0.80)	0.77 (0.60, 0.99)

Model 1: unadjusted.
Model 2: adjust for age, gender, race, education, and poverty income ratio.
Model 3: adjust for age, gender, race, education, poverty income ratio, smoking behavior; drinking behavior; physical activity, fiber supplement, energy intake, carbohydrate intake, SBP, DBP, HBP, BMI, WC, ALT, AST, BUN, SCR, TBIL, HBA1C, TG, TC, HDL-C, SUA, hyperlipidemia, CVD.
When stratifying subgroups for gender race and HBP, the stratification variables are not adjusted in the model.

was reduced by 11 % (log2 transformed), suggesting that there may be an association between dietary fiber intake and DN, but a causal relationship could not be established. In addition, dietary fiber intake showed a nonlinear U-shaped association with the prevalence of DN in male and non-Hispanic blacks. From the results, we have gained important insights into the possible relationship between

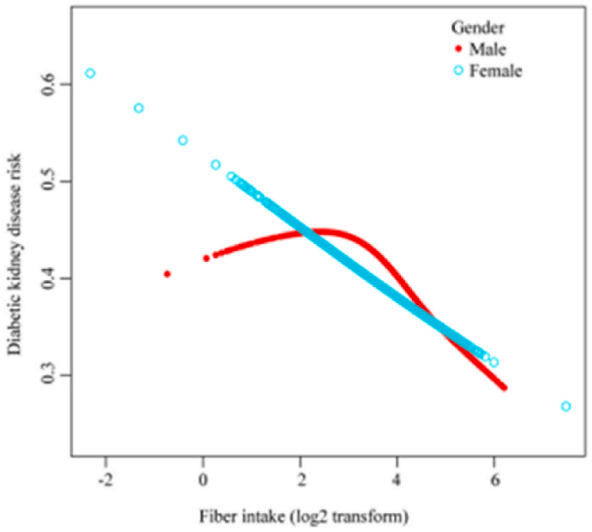

Fig. 3. Association between fiber intake and diabetic nephropathy stratified by gender (Model 3).

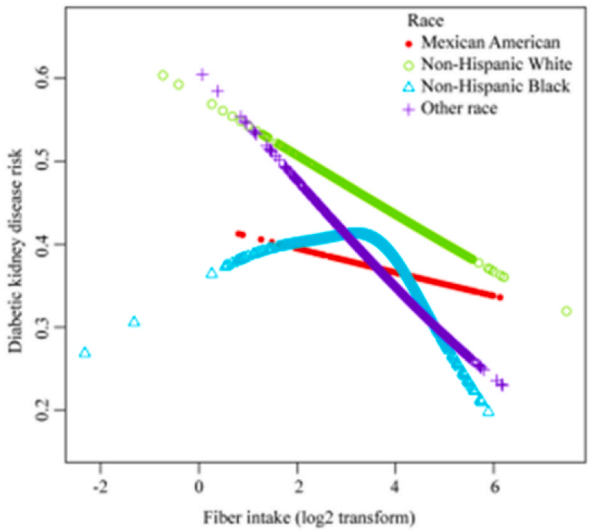

Fig. 4. Association between fiber intake and diabetic nephropathy stratified by race (Model 3).

dietary fiber intake and DN. Further confirmation is needed by causal studies.

According to this study, dietary fiber intake is negatively correlated with DN, which means that the more fiber you consume, the lower your risk for DN. Dietary fiber has been strongly associated with T2DM in recent epidemiological studies [26,27]. A study from a Danish cohort was conducted including 55,465 participants aged 50–65 years and followed them for 15 years. According to the researchers, eating whole grains reduced the risk of T2DM [28]. There was also a negative association between the total dietary fiber, soluble fiber, and insoluble fiber and the risk of T2DM in another prospective cohort study from France [29]. Studies have shown that dietary fiber reduces fasting blood glucose [30,31], which reduces the risk of albuminuria in diabetic patients and mortality in patients with DN [32,33]. In addition, high dietary fiber intake can reduce BUN and SCR levels [34,35], improve eGFR, and reduce the risk of chronic kidney disease [36,37]. A study suggests dietary fiber prevents DN through modulation of the gut microbiota's production of short-chain fatty acids (SCFA) and activation of G-protein-coupled receptors GPR43 and GPR109A [38,39]. In addition, dietary fiber may further protect renal function by altering the gut microbial community and reducing inflammation [15]. This probably partly explains the consistency of our findings. Therefore, patients who have been diagnosed with DM, by adjust their diet, especially by increasing the intake of dietary fiber. May help to better control blood glucose levels, thereby reducing the risk of complications such as DN. This is particularly important in the daily management of DM patients.

The second finding is that male, non-Hispanic Black showed a non-linear inverted U-shaped association. Appropriately increasing dietary fiber intake may reduce DN risk if it is on the right side of the inflection point. For males, there are differences in metabolism,

Table 5
Based on a two-piecewise linear regression model, the results indicate that fiber intake is related to Diabetic Nephropathy.

Fiber intake (log2 transform)	Adjusted OR (95 % CI)
Male	
The inflection points of fiber intake (g/d) (log2 transform)	3.0 (log_2 8.0)
Regression coefficients (≤ inflection point)	1.22 (0.85, 1.74)
Regression coefficients (> inflection point)	0.77 (0.64, 0.91)
P for log-likelihood ratio tests	0.033
Non-Hispanic Black	
Inflection points of fiber intake (g/d) (log2 transform)	3.9 (log_2 14.9)
Regression coefficients (≤ inflection point)	1.20 (0.93, 1.56)
Regression coefficients (> inflection point)	0.56 (0.35, 0.89)
P for log-likelihood ratio tests	0.006

adjust for age, gender, race, education, poverty income ratio, smoking behavior; drinking behavior; physical activity, fiber supplement, energy intake, carbohydrate intake, SBP, DBP, HBP, BMI, WC, ALT, AST, BUN, SCR, TBIL, HBA1C, TG, TC, HDL-C, SUA, Hyperlipidemia, CVD. When stratifying subgroups for gender and race, the stratification variables are not adjusted in the model.

hormonal and body composition, and activity, which may result in better maintaining stable blood glucose and kidney function after dietary fiber intake [40]. For non-Hispanic blacks, it may be related to genetic and environmental factors. The results of this study provide evidence of a complex relationship between dietary fiber and DN. To better understand this association, we need to further study different populations and the underlying biological mechanisms. We also emphasize the importance of personalized nutritional programs, which may require different dietary fiber intake recommendations for different populations.

This study has some limitations despite utilizing NHANES data and containing broad representative data. The first limitation of this study is that it is a cross-sectional study and cannot determine whether dietary fiber or DN are causally related. Although we observed an association, this does not mean that high dietary fiber intake directly led to a reduction in the prevalence of DN. Second, the 24-h recall method was used to collect dietary fiber intake and the diagnosis of DM was self-reported, so recall bias could have been introduced. Third, the findings may not apply to populations outside of the exclusion criteria, since we performed a series of nadir exclusion criteria. In addition, due to the complexity of the confounders, we could not rule out the influence of other potential confounders on the results of the study.

5. Conclusions

Dietary fiber intake may be associated with the risk of developing DN, and the relationship may depend on population characteristics. Our findings may emphasize that increasing dietary fiber intake may be an effective strategy for the management of DN. Our wish is that future studies, especially cohort studies or randomized controlled trials, will need to further validate this association and establish causality.

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Institutional review board Statement

The National Centre for Health Statistics' research ethics review board approved the NHANES study (https://www.cdc.gov/nchs/nhanes/irba98.htm).

Informed consent Statement

All the NHANES participants provided their written informed consent.

Data Availability Statement

The data used in this study are publicly available online (https://wwwn.cdc.gov/nchs/nhanes/, accessed on November 1, 2023).

CRediT authorship contribution statement

Hao Yang: Writing – original draft, Software. **Hong Lin:** Writing – original draft, Methodology. **Xiaorong Liu:** Validation. **Haoran Liu:** Validation. **Ting Chen:** Software. **Zhaohui Jin:** Writing – review & editing, Funding acquisition, Conceptualization.

Declaration of competing interest

I, [Hao Yang], declare that I have no conflicts of interest regarding the research presented in the manuscript entitled "[Title of Association Between Dietary Fiber Intake and Diabetic Nephropathy among Adults in the United States: A Cross-Sectional Study]." I confirm that I have no financial or personal relationships with individuals or organizations that could inappropriately influence or bias my work. Additionally, I have no competing interests, including but not limited to employment, consultancies, stock ownership, honoraria, paid expert testimony, patent applications/registrations, and grants or other funding.

Should any potential conflicts of interest arise during the review process or after publication, I will promptly disclose this information to the appropriate parties.

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