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Unveiling the correlation between dietary fiber intake and endometriosis: a cross-sectional analysis of NHANES data

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Endometriosis is a complex disorder characterized by genetic, immune, inflammatory, and multifactorial etiologies. Dietary fiber, a crucial component abundant in fruits, vegetables, and whole grains, is known for its diverse beneficial effects on weight control, inflammation, insulin resistance, lipid metabolism, and hormonal balance. However, the relationship between dietary fiber and endometriosis remains unclear. This study aimed to investigate the association between dietary fiber intake and endometriosis. This study utilized cross-sectional data obtained from the National Health and Nutrition Examination Survey, encompassing information from women aged 20–54 in the United States between1999 and 2006. After adjusting for relevant covariates, multivariable logistic regression analysis revealed a positive correlation between dietary fiber intake and the risk of endometriosis. Compared to individuals in the lowest quartile of dietary fiber intake (Q1: 0–7.8 g/day), the adjusted odds ratios (OR) for endometriosis were as follows: OR of 1.08 (95% CI 0.78–1.51, *P* = 0.639) for Q2 (7.9–11.9 g/day), OR of 0.98 (95% CI 0.69–1.39, *P* = 0.898) for Q3 (12.0–17.5 g/day), and OR of 1.73 (95% CI 1.13–2.63, *P* = 0.011) for Q4 (17.6–128.3 g/day). The trend test demonstrated a statistically significant positive trend in the risk of endometriosis with increasing dietary fiber intake, showing an OR of 1.15 (95% CI 1.01–1.31, *P* = 0.034). These findings suggest a positive association between endometriosis and dietary fiber intake. Further investigations are crucial to establish causality and elucidate the potential preventive benefits of dietary fiber intake in endometriosis.

Keywords Endometriosis, Dietary fiber, NHANES, Cross-sectional study, Multivariable logistic regression

Endometriosis, a prevalent inflammatory condition, is characterized by the presence of tissue resembling endometrial tissue outside the uterus on organs and tissues within the pelvic region[1]. Endometriosis is estimated to affect 10% of reproductive-age women[2], which extrapolates to approximately 190 million women worldwide, given the WorldBank's population estimates for 2017[3]. Based on NHANES data (1999–2006), the weighted prevalence of endometriosis in the United States was 9.4%[4]. Endometriosis is more common in 40–60% of women who have dysmenorrhea, 21–47% of women who are infertile, and 71–87% of women who have pelvic pain[5]. Notably, women with endometriosis incur healthcare costs more than twice as high as those without the condition[6]. Its widespread prevalence has led to its classification as a public health issue[7]. Although endometriosis significantly affects quality of life and healthcare costs[8], little is known about modifiable risk factors that can stop it from occurring. Due to effects on steroid hormones, inflammation, or food pollutants, dietary factors may play a part in the etiology of endometriosis.

Endometriosis is characterized by chronic inflammation and hormonal dysregulation, particularly involving estrogen metabolism[1]. Dietary fiber, an essential nutrient present in large quantities in fruits, vegetables, and whole grains, has been shown to benefit human health in a number of ways, including the management of inflammation, lipid metabolism, weight control, insulin resistance, and hormonal imbalances[9–12]. While dietary fiber is known for its anti-inflammatory properties and ability to modulate hormonal balance, it may also interact with these mechanisms in complex ways. For instance, high fiber intake can influence gut microbiota composition, potentially affecting estrogen metabolism and systemic inflammation in ways that are not yet fully understood[13]. Until now, there has been little research on the relationship between dietary fiber and endometriosis. To date, three studies have examined the associations between fruit and vegetable consumption and endometriosis risk, with differing findings. One case–control study reported lower fresh fruit and green

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vegetable intake in women with laparoscopically confirmed endometriosis[14]. Another population-based case–control study found no association with vegetable consumption but observed higher fruit intake among affected women[15]. A prospective cohort study suggested a non-linear inverse association between fruit consumption, particularly citrus fruits, and endometriosis risk, while certain vegetables (e.g., cruciferous) were linked to a higher risk[16].

The above three studies focused on the relationship between vegetable and fruit intake and endometriosis. As far as we know, there are no studies that specifically focus on the relationship between dietary fiber intake and endometriosis. This cross-sectional study aims to explore this connection among American women aged 20 to 54, utilizing a substantial sample size (4453 participants) to address these information gaps. Our findings aim to provide new insights into endometriosis prevention strategies in the United States.

Materials and methods

Data source

The National Health and Nutrition Examination Survey (NHANES) and the National Center for Health Statistics (NCHS) provided the data for this investigation. The investigation covered 4 consecutive 2-year NHANES cycles from 1999 to 2006. A nationally representative stratified sample gathered through interviews and physical examinations was used by NHANES. Ethical approval for the study was granted by the NCHS Ethics Review Committee. In accordance with ethical research guidelines, all study participants provided written informed consent.

Participants and definition

Endometriosis determination relied on participants' responses to a specific question in the reproductive health questionnaire: "Has a doctor or other health professional ever told you that you had endometriosis?" Participants answering affirmatively were categorized as patients. Since the questionnaire only addressed the relevant questions to individuals aged 20–54, our study population was limited to participants within this age range.

Dietary fiber assessment

Assessment of dietary fiber consumption was conducted through the NHANES dietary survey, a component of the "What We Eat in America" survey. This survey was carried out at the Mobile Examination Center (MEC) using a 24-h recall method administered by skilled interviewers. The NHANES computer-assisted dietary interview (CADI) system documented participants' food and beverage intake within the 24 h preceding the interview[18].

Participants were randomized, in accordance with the study design, to data collecting sessions that took place in the morning, afternoon, or evening. Nutritional intake and dietary fiber were assessed using the University of Texas Food Intake Analysis System and the US Department of Agriculture Survey Nutrients Database. It is important to note that pharmaceuticals or dietary supplements were excluded from nutritional calculations. Two 24-h dietary recall interviews were conducted, with a second interview completed 3–10 days later over the phone. The initial in-person interview at the MEC was chosen for analysis, given the widespread use of the 24-h recall method in large-scale surveys[19].

Measurements

Our study considered a comprehensive set of covariates, drawing from variables identified in the literature[20–22]. Age, marital status, race/ethnicity, education level, family income, smoking status, physical activity, BMI, alcohol consumption, use of birth control pills, high blood pressure, diabetes, coronary heart disease, chronic bronchitis, caloric consumption, total fat intake, total cholesterol intake, and usage of nutritional supplements were among these variables. Racial and ethnic categories included non-Hispanic white, non-Hispanic black, Mexican American, and other races. Marital status categories were defined as living with a partner or living alone. Educational attainment was stratified into fewer than nine years, nine to twelve years, and more than twelve years. Family income, assessed using the Poverty Income Ratio (PIR), categorized income into low, medium, and high based on ranges from 1.3 to 3.5, as per the US government's Agriculture report[23]. Smoking status was dichotomized into smokers and never smokers (defined as those who had smoked fewer than 100 cigarettes). Alcohol drinking status was determined by the survey question, "In any 1 year, have you had at least 12 drinks of any type of alcoholic beverage?" Participants who answered "yes" were defined as alcohol drinkers. Physical activity levels were categorized into three groups: unable to perform physical activity, moderate (defined as at least 10 min of movement within the previous 30 days resulting in only light perspiration or a mild to moderate increase in respiration or heart rate), and vigorous (at least 10 min of activity within the last 30 days resulting in profuse sweating or an increased heart rate). The determination of previous disease (high blood pressure, diabetes, coronary heart disease and chronic bronchitis) was based on the inquiry in the questionnaire of whether the doctor had been informed of the condition in the past.

Participants underwent a dietary recall interview before the Mobile Examination Center (MEC) interview to collect 24-h nutritional data, including calorie intake and macronutrients. Additionally, information on medications, including dietary supplements, taken in the previous month was collected.

Statistical analyses

This secondary analysis of publicly available datasets utilized descriptive statistics to characterize continuous variables (mean/SD or median/IQR) and proportions (%) for categorical variables. Group differences were assessed using Kruskal–Wallis tests and one-way analyses of variance. Logistic regression models were employed to investigate the relationship between dietary fiber intake and endometriosis across three models. Model 1 adjusted for sociodemographic (age, race/ethnicity, education level, family income and marital status). Model 2 was adjusted for Model 1 plus BMI, smoking status, vigorous activity, moderate activity, alcohol drinker, birth control pills taken, high blood pressure, diabetes, coronary heart disease and chronic bronchitis, and Model 3 was adjusted for Model 2 plus calorie consumption, total fat consumption, total cholesterol consumption and dietary supplements taken. These models aimed to comprehensively account for potential confounding factors and refine the understanding of the relationship between dietary fiber intake and endometriosis.

Potential modifiers of the association between dietary fiber intake and endometriosis were explored, incorporating variables such as family income (low vs. medium or high), marital status (living with a partner vs. living alone), smoking status, and dietary supplements taken. Multivariate logistic regression assessed heterogeneity among subgroups, and interactions between subgroups and dietary fiber intake were scrutinized through likelihood ratio testing.

To ensure the robustness of the findings, sensitivity analyses were conducted by excluding participants with extreme energy intake, defined as those consuming fewer than 500 or more than 5000 kcal per day. This meticulous approach aimed to evaluate the consistency and reliability of results under different conditions, enhancing the validity of study outcomes.

Sample size determination relied on available data, and no a priori statistical power assessments were carried out. Statistical analyses were performed using R 3.3.2, a statistical software program developed by The R Foundation, Shanghai, China (accessed on 10 January 2023), along with Free Statistics Software 1.5[24]. A two-tailed analysis was employed for hypothesis testing, with a significance level of 0.05 considered for determining statistical significance. This widely accepted threshold reflects a standard level of confidence in interpreting the results and drawing meaningful conclusions from the conducted analyses.

Results

Study population

The original dataset comprised 5557 female participants. After excluding individuals with missing endometriosis-related information and those falling outside the age range of 20 to 54 years, our final study population consisted of 4453 women. Among them, 337 were diagnosed with endometriosis, while 4116 were not. Exclusions were applied to 991 pregnant women, and 113 lacking information on dietary fiber intake. Figure 1 provides a detailed illustration of the inclusion and exclusion process.

Baseline characteristics

Table 1 outlines the fundamental characteristics of the 4453 participants in the study. Among the sample, 337 individuals (7.6%) received a diagnosis of endometriosis, and 2820 (63.3%) were categorized as overweight. A total of 1741 participants (39.1%) re-ported being smokers, while 2099 (47.1%) acknowledged the use of dietary supplements. Regarding age distribution, 2378 participants (53.4%) were below 40 years old, 1424 (32%) were between 40 and 50 years old, and 651 (14.6%) were above 50 years old. Notably, dietary fiber intake appeared

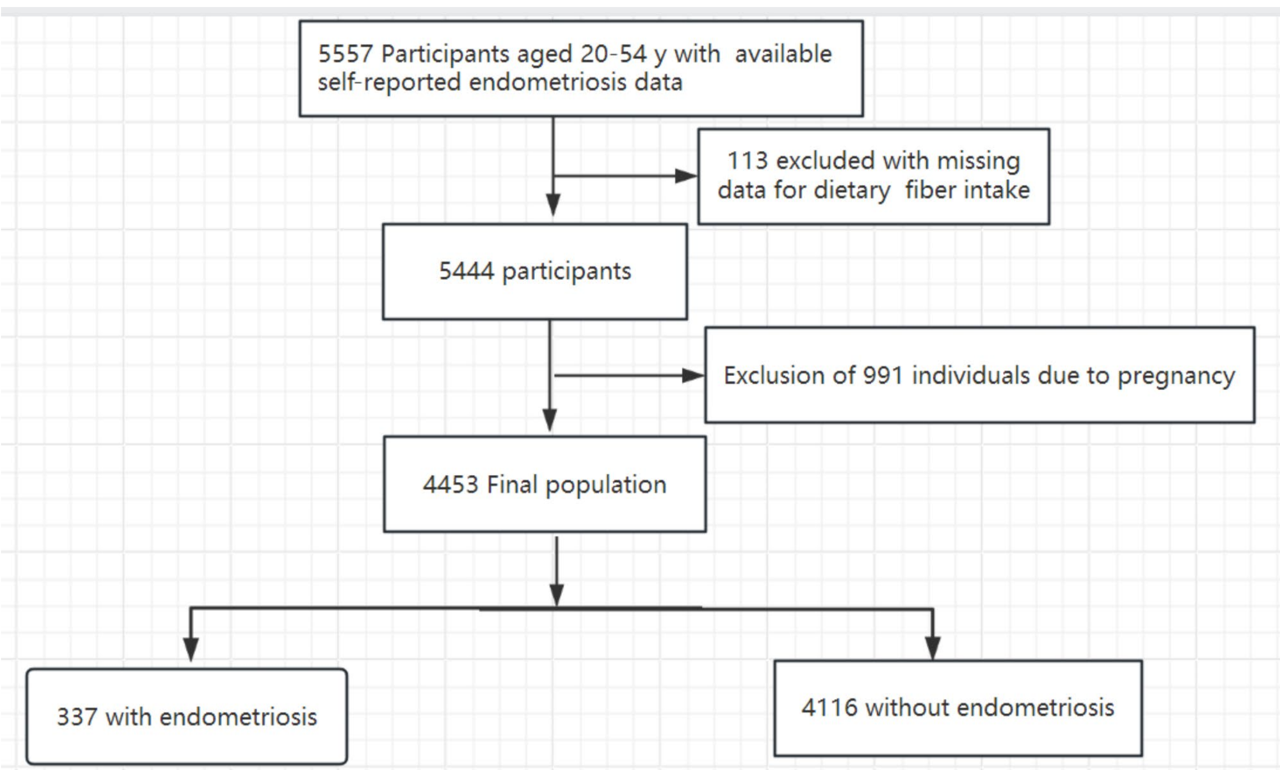

Fig. 1. The study's flow diagram.

Variables	Total	Dietary fiber intake (g/d) Q1 (0–7.8)	Q2 (7.9–11.9)	Q3 (12.0–17.5)	Q4 (17.6–128.3)	*p*
NO	4453	1091	1127	1121	1114	
Age (year), n (%)						0.259
< 40	2378 (53.4)	601 (55.1)	608 (53.9)	606 (54.1)	563 (50.5)	
40–50	1424 (32.0)	344 (31.5)	355 (31.5)	360 (32.1)	365 (32.8)	
> 50	651 (14.6)	146 (13.4)	164 (14.6)	155 (13.8)	186 (16.7)	
BMI(Kg/m^2), n (%)						0.22
< 25	1592 (36.1)	371 (34.5)	383 (34.2)	412 (37.1)	426 (38.5)	
25–30	1185 (26.9)	284 (26.4)	304 (27.1)	306 (27.5)	291 (26.3)	
> 30	1635 (37.1)	420 (39.1)	433 (38.7)	393 (35.4)	389 (35.2)	
Race/Ethnicity, n (%)						< 0.001
Mexican American	1006 (22.6)	175 (16)	213 (18.9)	273 (24.4)	345 (31)	
Other Race	400 (9.0)	86 (7.9)	120 (10.6)	98 (8.7)	96 (8.6)	
Non-Hispanic White	2051 (46.1)	478 (43.8)	500 (44.4)	548 (48.9)	525 (47.1)	
Non-Hispanic Black	996 (22.4)	352 (32.3)	294 (26.1)	202 (18)	148 (13.3)	
Family Income, n (%)						< 0.001
Low	1177 (28.3)	347 (34.2)	294 (27.9)	287 (27.4)	249 (23.8)	
Medium	1521 (36.5)	386 (38)	400 (38)	361 (34.5)	374 (35.7)	
High	1464 (35.2)	283 (27.9)	358 (34)	399 (38.1)	424 (40.5)	
Education Level(year), n (%)						< 0.001
< 9	383 (8.6)	72 (6.6)	74 (6.6)	104 (9.3)	133 (11.9)	
9–12	1695 (38.1)	514 (47.1)	462 (41)	392 (35)	327 (29.4)	
> 12	2371 (53.2)	504 (46.2)	589 (52.3)	624 (55.7)	654 (58.7)	
Marital status, n (%)						< 0.001
Living with a partner	2613 (58.7)	558 (51.1)	644 (57.1)	692 (61.7)	719 (64.5)	
Living alone	1728 (38.8)	498 (45.6)	453 (40.2)	406 (36.2)	371 (33.3)	
Smoking status, n (%)						< 0.001
Yes	1741 (39.1)	521 (47.8)	468 (41.5)	386 (34.4)	366 (32.9)	
No	2709 (60.8)	569 (52.2)	659 (58.5)	734 (65.5)	747 (67.1)	
Vigorous activity, n (%)						< 0.001
Yes	1509 (33.9)	313 (28.7)	387 (34.3)	383 (34.2)	426 (38.2)	
No	2855 (64.1)	742 (68)	717 (63.6)	723 (64.5)	673 (60.4)	
Unable to do activity	87 (2.0)	35 (3.2)	23 (2)	15 (1.3)	14 (1.3)	
Moderate activity, n (%)						< 0.001
Yes	2320 (52.1)	498 (45.6)	580 (51.5)	605 (54)	637 (57.2)	
No	2065 (46.4)	566 (51.9)	530 (47)	503 (44.9)	466 (41.8)	
Unable to do activity	66 (1.5)	27 (2.5)	17 (1.5)	12 (1.1)	10 (0.9)	
Alcohol drinker, n (%)						0.314
Yes	2748 (61.7)	670 (61.4)	714 (63.4)	694 (61.9)	670 (60.1)	
No	1703 (38.2)	421 (38.6)	411 (36.5)	427 (38.1)	444 (39.9)	
Dietary supplements taken, n (%)						< 0.001
Yes	2099 (47.1)	431 (39.5)	511 (45.4)	549 (49)	608 (54.6)	
No	2350 (52.8)	660 (60.5)	614 (54.5)	572 (51)	504 (45.2)	
Birth control pills taken, n (%)						0.182
Yes	3362 (75.5)	827 (75.8)	866 (76.8)	857 (76.4)	812 (72.9)	
No	1087 (24.4)	262 (24)	261 (23.2)	263 (23.5)	301 (27)	
High blood pressure, n (%)						0.47
Yes	867 (19.5)	234 (21.4)	229 (20.3)	201 (17.9)	203 (18.2)	
No	3558 (79.9)	850 (77.9)	893 (79.2)	913 (81.4)	902 (81)	
Diabetes, n (%)						0.194
Yes	236 (5.3)	48 (4.4)	69 (6.1)	50 (4.5)	69 (6.2)	
No	4176 (93.8)	1030 (94.4)	1046 (92.8)	1065 (95)	1035 (92.9)	
Coronary heart disease, n (%)						0.888
Yes	37 (0.8)	11 (1)	8 (0.7)	11 (1)	7 (0.6)	
No	4413 (99.1)	1080 (99)	1118 (99.2)	1109 (98.9)	1106 (99.3)	
Chronic bronchitis, n (%)						0.016
Continued						

Variables	Total	Dietary fiber intake (g/d)				p
		Q1 (0–7.8)	Q2 (7.9–11.9)	Q3 (12.0–17.5)	Q4 (17.6–128.3)	
Yes	317 (7.1)	103 (9.4)	76 (6.7)	73 (6.5)	65 (5.8)	
No	4128 (92.7)	987 (90.5)	1047 (92.9)	1046 (93.3)	1048 (94.1)	
Calorie consumption(kcal/d), Mean (SD)	1911.9 ± 816.1	1351.4 ± 574.7	1787.5 ± 625.5	2079.9 ± 737.9	2417.5 ± 888.2	< 0.001
Total cholesterol consumption(mg/d), Median (IQR)	194.0 (114.0, 329.0)	147.9 (83.5, 269.7)	195.9 (117.0, 312.9)	218.0 (136.0, 364.7)	214.0 (130.0, 358.5)	< 0.001
Total fat consumption(g/d), Median (IQR)	66.0 (45.4, 91.8)	47.5 (30.4, 67.6)	64.2 (46.0, 87.0)	73.7 (54.2, 98.5)	81.1 (57.2, 111.7)	< 0.001

Table 1. Population characteristics by categories of dietary fiber intake. Data are presented as mean(SD) or n (%).

Variable	OR_95CI	P_value	Variable	OR_95CI	P_value
Age (year), n (%)			Moderate activity, n (%)		
< 40	1 (reference)		Yes	1 (reference)	
40–50	0.53 (0.42–0.68)	< 0.001	No	1.21 (0.96–1.51)	0.108
> 50	0.54 (0.39–0.74)	< 0.001	Unable to do activity	0.49 (0.25–0.98)	0.043
BMI (Kg/m^2), n (%)			Dietary supplements taken, n (%)		
< 25	1 (reference)		Yes	1 (reference)	
25–30	0.94 (0.71–1.24)	0.671	No	1.59 (1.27–1.99)	< 0.001
> 30	1.07 (0.82–1.39)	0.629	Diabetes, n (%)		
Family Income, n (%)			Yes	1 (reference)	
Low	1 (reference)		No	0.76 (0.44–1.32)	0.33
Medium	0.79 (0.57–1.08)	0.134	Birth control pills taken, n (%)		
High	0.51 (0.38–0.69)	< 0.001	Yes	1 (reference)	
Race/Ethnicity, n (%)			No	2.77 (1.95–3.93)	< 0.001
Mexican American	1 (reference)		Coronary heart disease, n (%)		
Other Race	0.65 (0.35–1.19)	0.162	Yes	1 (reference)	
Non-Hispanic White	0.23 (0.15–0.34)	< 0.001	No	1.92 (0.74–4.96)	0.178
Non-Hispanic Black	0.42 (0.27–0.67)	< 0.001	Chronic bronchitis, n (%)		
Education Level (year), n (%)			Yes	1 (reference)	
< 9	1 (reference)		No	2.67 (1.93–3.67)	< 0.001
9–12	0.19 (0.08–0.43)	< 0.001	High blood pressure, n (%)		
> 12	0.17 (0.08–0.39)	< 0.001	Yes	1 (reference)	
Marital Status, n (%)			No	1.61 (1.25–2.07)	< 0.001
Living with a partner	1 (reference)		Dietary fiber intake(g/d)	1.02 (1.01–1.04)	0.003
Living alone	1.23 (0.97–1.55)	0.082	Calorie consumption(kcal/d)	1 (1–1)	0.296
Vigorous activity, n (%)			Total fat consumption(g/d)	1 (1–1)	0.651
Yes	1 (reference)		Total cholesterol consumption(mg/d)	1 (1–1)	0.072
No	0.97 (0.77– 1.24)	0.835			
Unable to do activity	0.55 (0.28–1.06)	0.075			

Table 2. Association of covariates and endometriosis risk.

to be higher in individuals who used dietary supplements, engaged in exercise, lived with a partner, had a higher income, were older than 50 years, had a BMI < 25, and had an education level < 9 years or > 12 years. These baseline characteristics offer an overview of the diversity within the study population and establish the foundation for subsequent analyses exploring the association between these factors and endometriosis.

Relationship between dietary fiber intake and endometriosis

Table 2 presents the relationships between dietary fiber intake and endometriosis. The univariate analysis revealed significant associations, indicating that dietary fiber intake, age, family income, race, education level, use of birth control pills, high blood pressure, chronic bronchitis, and dietary supplements taken were correlated with the presence of endometriosis. These findings highlight a complex interplay between dietary factors, demographic variables, and lifestyle choices influencing the occurrence of endometriosis. Subsequent multivariate analyses will further dissect these associations to elucidate the independent contributions of each factor to the risk of endometriosis.

In comparison to individuals with lower dietary fiber consumption (Q1 < 7.8 g/day), and with adjustments for age, marital status, race/ethnicity, education level, family income, smoking status, physical activity, BMI, alcohol consumption, use of birth control pills, high blood pressure, diabetes, coronary heart disease, chronic bronchitis, caloric consumption, total fat intake, total cholesterol intake, and usage of nutritional supplements, the adjusted odds ratios (OR) for endometriosis in the Q2 (7.9–11.9 g/day) and Q3 (12.0–17.5 g/day) groups were 1.08 (95% CI 0.78–1.51, $P = 0.639$) and 0.98 (95% CI 0.69–1.39, $P = 0.898$), respectively. The highest quartile, Q4 (17.6–128.3 g/day), showed a significant increase with an OR of 1.73 (95% CI 1.13–2.63, $P = 0.011$) (Table 3). A significant positive trend across increasing fiber intake suggests an association between higher dietary fiber consumption and an increased risk of endometriosis (OR = 1.15; 95% CI 1.01–1.31, $P = 0.034$) (Table 3).

Stratified analyses based on additional variables

In a meticulous examination of various subgroups, we conducted stratified analyses to assess potential modifications in the relationship between dietary fiber intake and endometriosis (refer to Fig. 2). Remarkably, no significant interactions were detected in any subgroups, irrespective of stratification by age, race, BMI, marital status, family income, smoking status, education level, or dietary supplements taken. These results suggest that the observed association between dietary fiber intake and endometriosis holds consistently across diverse demographic and lifestyle factors, reinforcing the robustness of the findings.

Sensitivity analysis

The sensitivity analysis involved 4375 individuals after excluding those with daily caloric intakes below 500 kcal or above 5000 kcal. The adjusted odds ratios (OR) for endometriosis compared to the lowest fiber intake group (Q1 < 7.8 g/day) were 1.11 (95% CI 0.79–1.54, $P = 0.546$) for Q2 (7.9–11.9 g/day), 1.04 (95% CI 0.73–1.49, $P = 0.811$) for Q3 (12.0–17.5 g/day), and 1.74 (95% CI 1.14–2.63, $P = 0.010$) for Q4 (17.6–128.3 g/day). These findings demonstrate a statistically significant positive trend (OR = 1.16; 95% CI 1.02–1.32, $P = 0.024$) in endometriosis risk with increasing dietary fiber intake, reinforcing the relationship's robustness against dietary energy variations Detailed results of this analysis are provided in the Supplementary Materials.

Moreover, we have expanded our sensitivity analysis to include a stratified approach by several potential modifiers, such as age, BMI, family income, race/ethnicity, and smoking status. Each subgroup was further analyzed across quartiles of dietary fiber intake to comprehensively assess potential variations in the association between dietary fiber intake and the risk of endometriosis. These findings from the sensitivity analysis underscore the complexity of the relationship between dietary fiber intake and endometriosis risk, suggesting that individual characteristics such as age, BMI, income, and race might influence this association Detailed results of the stratified analysis are provided in the Supplementary Materials.

Discussion

In this extensive cross-sectional study involving American adults, a noteworthy and previously unexplored positive correlation between endometriosis and dietary fiber intake was identified. After stratified analysis, these associations were more significant among patients < 40 years of age, middle-income families, 9–12 years of education level, living alone, and not eligible for dietary supplements taken. The sensitivity analysis confirmed the robustness of our findings, with the highest quartile of dietary fiber intake (Q4) consistently associated with a significantly increased risk of endometriosis. This association may reflect a non-linear relationship influenced by extremes in dietary intake, gut microbiota composition, estrogen metabolism, or unmeasured dietary patterns. Future longitudinal or interventional studies are needed to further explore these mechanisms and validate the findings.

Dietary fiber, a vital component abundant in fruits, vegetables, and whole grains, manifests multiple beneficial effects on human health. These benefits encompass regulation of body weight, modulation of inflammation, improvement of insulin sensitivity, lipid metabolism, and hormonal regulation[10–13]. Prior research indicates that a high-fiber diet lowers serum estrogen levels in premenopausal women[25,26]. Observational studies have posited that plant-based and fiber-rich diets promote estrogen excretion and diminish levels of bioavailable estrogen, potentially reducing endometriosis risk[27,28]. Dietary fiber exerts a profound influence on human health by modulating gut microbial ecology and host physiology[29]. Certain gut bacteria, by fermenting dietary fiber,

Variable	OR(95%CI)						
	NO	Model 1	*P*-value	Model 2	*P*-value	Model 3	*P*-value
Dietary fiber intake(g/day)	4453	1.03 (1.01–1.04)	0.001	1.02 (1.01–1.04)	0.006	1.03 (1.01–1.05)	0.003
Q1(0–7.8)	1091	1(Ref)		1(Ref)		1(Ref)	
Q2(7.9–11.9)	1127	1.1 (0.8–1.51)	0.551	1.05 (0.76–1.46)	0.748	1.08 (0.78–1.51)	0.639
Q3(12.0–17.5)	1121	1.01 (0.74–1.38)	0.96	0.95 (0.69–1.31)	0.754	0.98 (0.69–1.39)	0.898
Q4(17.6–128.3)	1114	1.74 (1.21–2.48)	0.002	1.61 (1.12–2.31)	0.01	1.73 (1.13–2.63)	0.011
Trend test	4453	1.15 (1.04–1.28)	0.009	1.13 (1.01–1.26)	0.033	1.15 (1.01–1.31)	0.034

Table 3. Association between dietary fiber intake and endometriosis. Q, quartiles; OR, odds ratio; CI, confidence interval; Ref: reference. Model 1 adjusted for sociodemographic (age, race/ethnicity, education level, family income and marital status).Model 2 was adjusted for Model 1 plus BMI, smoking status, vigorous activity, moderate activity, alcohol drinker, birth control pills taken, high blood pressure, diabetes, coronary heart disease and chronic bronchitisModel 3 was adjusted for Model 2 plus calorie consumption, total fat consumption, total cholesterol consumption and dietary supplements taken.

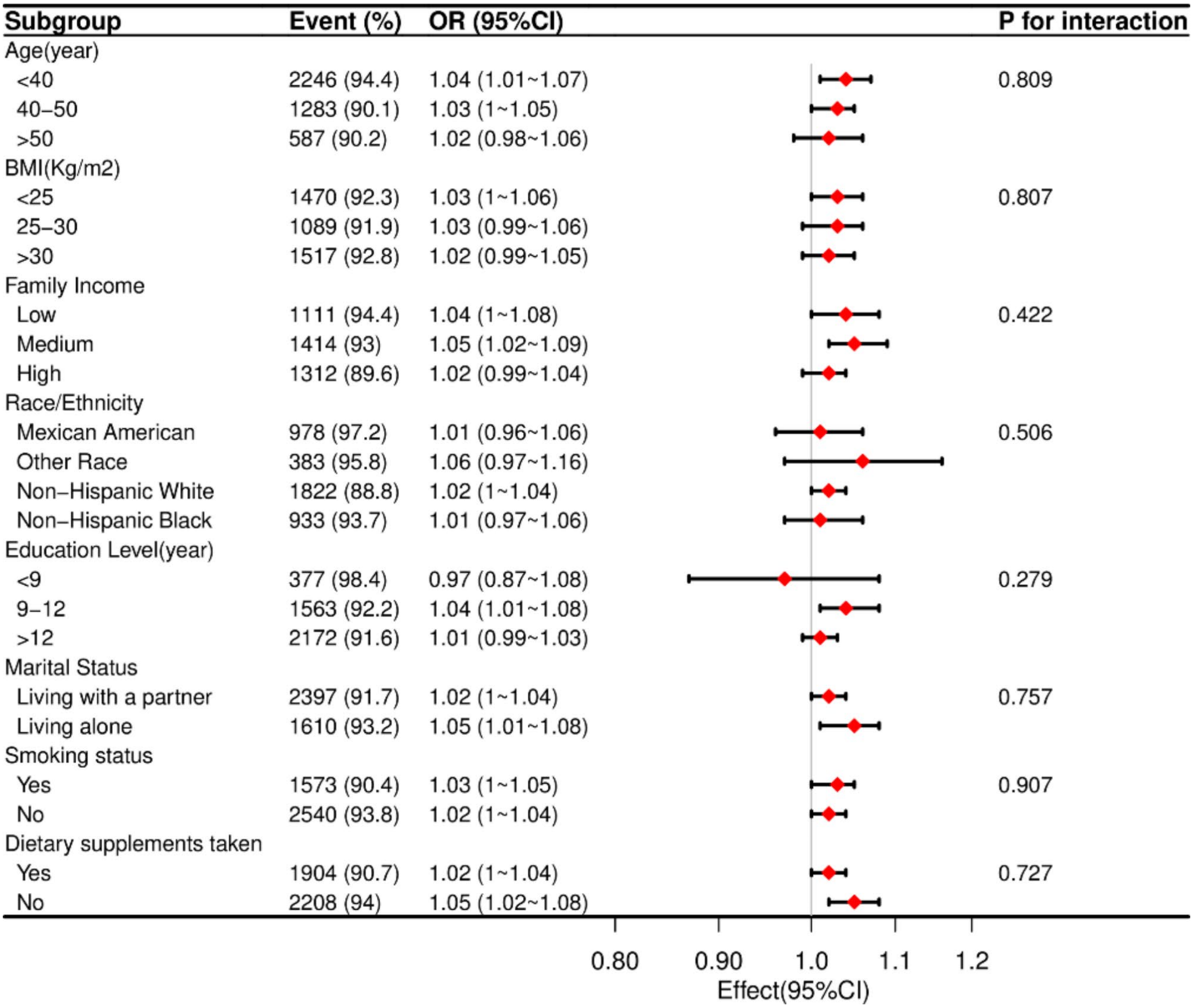

Fig. 2. The relationship between dietary fiber intake and endometriosis according to basic features. Except for the stratification component itself, each stratification factor was adjusted for all other variables (age, marital status, race/ethnicity, education level, family income, BMI, calorie consumption, vigorous activity, moderate activity, dietary supplements taken and smoking status).

generate short-chain fatty acids, which confer protection against endometriosis[30]. Epidemiological evidence robustly links a high intake of dietary fiber to a decreased risk of several chronic inflammatory diseases[31], noting that the beneficial effects vary depending on the types of fibers and their dietary sources[32–34]. For instance, insoluble fibers and those derived from cereals are strongly inversely associated with the risk of coronary heart disease[32], whereas the most significant benefits for conditions like Crohn's disease and diverticulitis are noted with fruit fibers [33,34]. Not all fibers exert equivalent effects. Both in vitro and in vivo studies have demonstrated that structural variances in dietary fibers can trigger distinct anti-inflammatory responses[35–37]. For example, apple-derived pectin, compared to inulin, distinctly influences gut microbiome composition and significantly promotes Eubacterium eligens[35]. Recent experimental findings have further clarified the role of dietary fiber in influencing gut microbiota composition and its involvement in the pathogenesis of inflammation by impairing intestinal barrier function and enhancing permeability[38–40]. These insights collectively provide compelling human evidence supporting diverse fiber-gut-microbiome interactions pertinent to chronic systemic inflammation [41]. The study suggests that high dietary fiber intake may mitigate the risk of chronic inflammatory diseases such as cardiovascular disease and inflammatory bowel disease, partly by alleviating chronic systemic inflammation induced by gut microbiota dysbiosis[41].

Few human research has examined the relationship between endometriosis and food, with inconsistent results for the dietary components that were examined. To our knowledge, there are currently few studies that specifically look at the relationship between dietary fiber intake and endometriosis. There are currently three ancillary research investigating the relationship between consumption of fruits and vegetables and endometriosis. Women with endometriosis were found to consume more fruit in a population-based case–control research conducted in Washington state, USA, but there was no link with vegetable consumption[15]. On the other hand, those who had endometriosis confirmed laparoscopically showed a significantly lower consumption of fresh fruit and green vegetables[14]. Trabert et al.[15] suggested that the elevated risk of endometriosis observed in their study could potentially be attributed to pesticide exposure through fruit consumption. Furthermore, a prospective cohort study[16] that included information from 70,835 premenopausal women gathered as part of the Nurses' Health Study II cohort between 1991 and 2013 revealed a non-linear inverse relationship between the risk of endometriosis confirmed by laparoscopy and increased fruit consumption. With citrus fruits, this inverse connection was particularly noticeable. In contrast, there was a higher incidence of endometriosis linked to the consumption of corn, cruciferous vegetables, and peas/lima beans. Harris et al.[16] explain that beta-cryptoflavin in fruits may reduce the risk of endometriosis, while consumption of some vegetables increases the risk of endometriosis, possibly because gastrointestinal symptoms make endometriosis-related pain worse.

Although our study's findings differ from previous research, there may be more complex mechanisms influencing the relationship between dietary fiber and endometriosis. Firstly, phytoestrogens are plant-derived compounds with estrogenic properties, primarily falling into two groups: isoflavones and lignans, abundantly present in the human diet. While initially recognized for their mild estrogenic activity, many of these compounds exhibit various other biological activities that could potentially impact disease risk[42,43]. In a particular study[44], cereal fiber demonstrated a more pronounced positive association with endometrial cancer risk in postmenopausal women, although the trend was not distinctly clear. Similarly, a different study[45] found a link between eating cereal fiber and a lower risk of endometrial cancer.

Secondly, polysaccharides such as cellulose, pectin, and beta-glucans are easily broken down by the microbiota in the colon but resist digestion by enzymes in the small intestine. The gut microbiota can modify the kinds or content of hormones in circulation and increase their levels through deconjugation by means of processes including hydroxylation/dehydroxylation and methylation/demethylation[46]. The types and quantities of circulating steroid hormones may be influenced by the makeup of the gut microbiota, potentially increasing the risk of endometriosis at high levels. Additionally, a small number of investigations employing animal models indicate that the consumption of fiber and/or the metabolites it produces may be detrimental to the health of the host in some circumstances, such as colitis[47] and/or colon cancer[48]. While the majority of the research on the health effects of fiber is positive, there may be some situations in which generalizations should be made with care. It is crucial to emphasize that tolerance to dietary fiber varies among individuals and frequently gets better with time as the gastrointestinal tract and microbiota adjust to higher dietary fiber intake[49].

Thirdly, it has been demonstrated that excessive consumption of certain rapidly fermenting fibers can lead to the accumulation of metabolites known as short-chain fatty acids (SCFAs), which may be detrimental to the mucosa of the intestines. This phenomenon could compromise the integrity of the intestinal barrier, induce mucosal inflammation, and heighten the sensitivity of the viscera[50]. Another study indicated that the ingestion of short-chain oligofructose increased intestinal permeability, although this effect was confined to the colon[51]. A study from France revealed that mice fed either oligofructose or lactose exhibited heightened numbers of mucosal mast cells in the proximal colon compared to the control group, accompanied by increased ab-dominal sensitivity. The activation of mast cells triggers the release of pro-inflammatory cytokines, such as IL-10 and IL-33, into the local environment. This series of events leads to elevated levels of inflammation in the body, which may be associated with endometriosis.

Our study has some strengths. It is the first research explicitly examining the as-sociation between dietary fiber consumption and endometriosis. We identified a positive correlation between dietary fiber intake and endometriosis, and these results remained robust after conducting multiple regression and sensitivity analyses. However, our study is not without limitations. Firstly, one important restriction is the dearth of data on the relationship between endometriosis risk and other fiber subtypes, like soluble fiber, cellulose, and lignin. Secondly, the 24-h dietary recall interviews introduces measurement errors that may impact the results. Additionally, the cross-sectional design of our study precludes the ability to establish causality or assess the temporal relationship between dietary fiber intake and endometriosis risk. Moreover, the diversity and composition of gut microbiota could potentially modify the effects of dietary fiber on endometriosis risk. Dietary fiber serves as a substrate for microbial fermentation, generating metabolites such as SCFAs that influence systemic inflammation, immune modulation, and estrogen metabolism—critical pathways in endometriosis development. The absence of microbiome data in this study limits our ability to account for these potential interactions. Future research incorporating microbiome profiling could provide valuable insights into the complex relationship between dietary fiber intake, gut microbiota, and endometriosis.

Conclusion

In summary, our findings highlight a positive association between dietary fiber intake and endometriosis risk. This study underscores the need for further exploration of underlying mechanisms and the development of targeted preventive measures.

Data availability

The datasets used in this study are publicly available and can be accessed through the National Health and Nutrition Examination Survey (NHANES) repository at https://wwwn.cdc.gov/nchs/nhanes/default.aspx (accessed on March 5, 2024). Detailed information about the survey design, data collection, and variables is available on this website.

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Author contributions

B.X. and Y.H. wrote the main manuscript text. J.H. and L.F. prepared the analysis and methodology. Y.W. and X.L. contributed to data curation and formal analysis. Y.W. and L.F. reviewed and edited the manuscript. All authors have read and agreed to the published version of the manuscript.

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Declarations

Competing interests

The authors declare no competing interests.

Ethics statement

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Additional information

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