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Original article

Association of dietary fiber intake with all-cause and cardiovascular mortality in postmenopausal U.S. women: A NHANES 1999–2018 cohort study

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ABSTRACT

Background: Dietary fiber is known to confer various health benefits, yet its impact on long-term mortality in older women remains under-explored. This study investigated the association between dietary fiber intake and the risk of all-cause and cardiovascular disease (CVD) mortality among postmenopausal U.S. women.

Methods: We analyzed 7708 postmenopausal participants from the 1999–2018 National Health and Nutrition Examination Survey (NHANES) linked to mortality data (median follow-up 121 months). Dietary fiber intake (grams/day) was assessed via 24-h dietary recalls. Cox proportional hazards models estimated hazard ratios (HRs) for all-cause and CVD mortality, adjusting for factors such as age, sex, ethnicity, education, poverty-income ratio, smoking, alcohol use, physical activity, and body mass index.

Results: The mean baseline dietary fiber intake was 14.75 ± 7.5 g/day. During follow-up, 2116 deaths (27.5 %) occurred, including 657 CVD deaths (8.5 %). Fiber intake was inversely associated with mortality risk. For those consuming less than 7.9 g/day, each 5 g/day increase in fiber was linked to a 7 % reduction in all-cause mortality risk (HR = 0.93). Above 7.9 g/day, benefits diminished (HR = 0.99). Women in the highest fiber tertile had significantly lower mortality risks than those in the lowest tertile (all-cause HR = 0.85; CVD HR = 0.69).

Conclusion: Higher dietary fiber intake is associated with reduced all-cause and CVD mortality, emphasizing the importance of adequate fiber consumption to older women's health and longevity.

1. Introduction

Dietary fiber is a key component of a healthy diet and has been linked to multiple health benefits, including improved cardiovascular and metabolic health [1]. High intake of dietary fiber has been associated with reduced risks of coronary heart disease, type 2 diabetes, certain cancers, and mortality. A comprehensive 2024 meta-analysis of 64 prospective cohort studies found that individuals with the highest fiber consumption had a 23 % lower risk of all-cause mortality compared to those with the lowest fiber intake Similarly, fiber intake has been inversely associated with cardiovascular disease (CVD) mortality in diverse populations [2]. These epidemiological observations align with known physiological effects of fiber, such as improving blood lipid profiles, enhancing glycemic control, and reducing inflammation (mechanisms discussed further below).

Postmenopausal women are an important demographic for studying fiber and health outcomes. After menopause, women experience an increase in CVD risk and other metabolic changes, potentially heightening the importance of protective dietary factors like fiber. Dietary guidelines recommend a fiber intake of approximately 21–25 g per day for adult women **[3]**. However, actual fiber consumption in the United States is far below these recommendations – the average American adult consumes only about 15 g of fiber daily, roughly half the advised amount [3]. Older women tend to have particularly low fiber intakes due to lower food intake and possible diet limitations [4]. Insufficient fiber consumption in this population may contribute to higher risks of chronic diseases and mortality [5]. Improving fiber intake could be a modifiable strategy to enhance health and longevity in postmenopausal women.

While prior studies (including large cohorts and meta-analyses) have demonstrated an overall inverse relationship between fiber intake and mortality [6], there is limited information on how this association manifests specifically in postmenopausal women and whether there are intake thresholds beyond which additional fiber confers little extra benefit. Some evidence suggests the mortality risk reduction from fiber

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might plateau at higher intake levels. For example, one dose–response analysis indicated that the greatest risk reduction occurred at ~25–29 g/day of fiber, with further gains tapering off beyond 30 g/day [7]. It is unclear if a similar or different non-linear pattern exists in older women, especially given their generally lower range of intake.

In this context, we aimed to examine the association between dietary fiber intake and the risk of all-cause and CVD-specific mortality among U.S. postmenopausal women using nationally representative National Health and Nutrition Examination Survey (NHANES) data (1999–2018 cycles). We sought to quantify the hazard ratios for mortality associated with fiber intake, evaluate potential non-linear (threshold) effects, and determine the difference in mortality risk between low and high fiber consumers in this population. We hypothesized that higher fiber intake would be associated with lower mortality risk and that the benefit of fiber might plateau at higher intake levels. Understanding these patterns can inform dietary recommendations and interventions targeted at improving fiber intake in older adult populations.

2. Materials and methods

2.1. Study design and population

We conducted an observational cohort analysis using data from the NHANES 1999–2018, a program of cross-sectional surveys of the U.S. civilian, non-institutionalized population. Although NHANES is cross-sectional in design, participants from these survey cycles have been prospectively followed for mortality outcomes through a probabilistic linkage to the National Death Index. For this analysis, we combined ten NHANES cycles (1999–2000 through 2017–2018) to assemble a cohort and followed participants for mortality status up to the latest available follow-up (through December 31, 2019, as per NDI linkage). The follow-up time for each individual was calculated from the NHANES examination date to the date of death or end of follow-up, whichever came first.

The study population was restricted to postmenopausal women. We defined postmenopausal status based on self-reported cessation of menses (natural or surgical menopause) or age $\geq$ 50 years with no menstrual periods in the past 12 months. Men were not included in this analysis. Among eligible female participants across 1999–2018, we excluded individuals with missing dietary data or implausible caloric intake (to ensure reliable dietary recall), those with missing covariate information, and anyone who had prevalent cardiovascular disease or cancer at baseline (to reduce reverse causation bias, as severe illness can affect diet). After exclusions, a total of 7708 postmenopausal women were included in the analytic cohort, as shown in Fig. 1. The mean age was 64.4 years (standard deviation 11.3). The study sample was ethnically diverse and reflected the U.S. population distribution through NHANES's complex sampling design.

2.2. Exposure assessment

The primary exposure was total dietary fiber intake (grams per day). NHANES participants complete 24-h dietary recalls administered by trained interviewers using a standardized methodology (the USDA Automated Multiple-Pass Method). In most NHANES cycles, two non-consecutive 24-h recalls are collected (one in-person and one via telephone), but for consistency we utilized the first recall for all participants as the measure of baseline dietary intake. The total fiber intake (in grams) reported from all foods and beverages consumed in that 24-h period was used as the exposure variable. This captures fiber from naturally fiber-rich foods (fruits, vegetables, whole grains, legumes, nuts) as well as any added fiber in processed foods. While a single-day intake may not perfectly represent long-term habitual intake, prior research indicates that on average it provides a reasonable ranking of individuals' fiber consumption, especially in large samples.

In our cohort, the mean fiber intake was 14.75 g/day (SD 7.5), and the median was 13.6 g/day. As expected, intake was well below recommended levels for most participants. We observed a wide range of fiber consumption (from extremely low <5 g up to ~50 g/day), though the majority of women fell in the lower intake end of the spectrum. We categorized fiber intake in several ways for analysis: (1) as a continuous variable (per 5 g/day increment) allowing for non-linear effects, and (2) as a categorical variable by tertiles of intake (low, medium, high) to compare higher vs. lower fiber consumers. Cut-off values for tertiles were determined based on the distribution of fiber intake in the cohort; the lowest tertile encompassed roughly <10 g/day, the middle ~10–~18 g/day, and the highest tertile >18 g/day (these are approximate boundaries, as exact tertile cutpoints were derived from the data).

2.3. All-cause mortality and cardiovascular mortality

The primary outcome was all-cause mortality, defined as death from

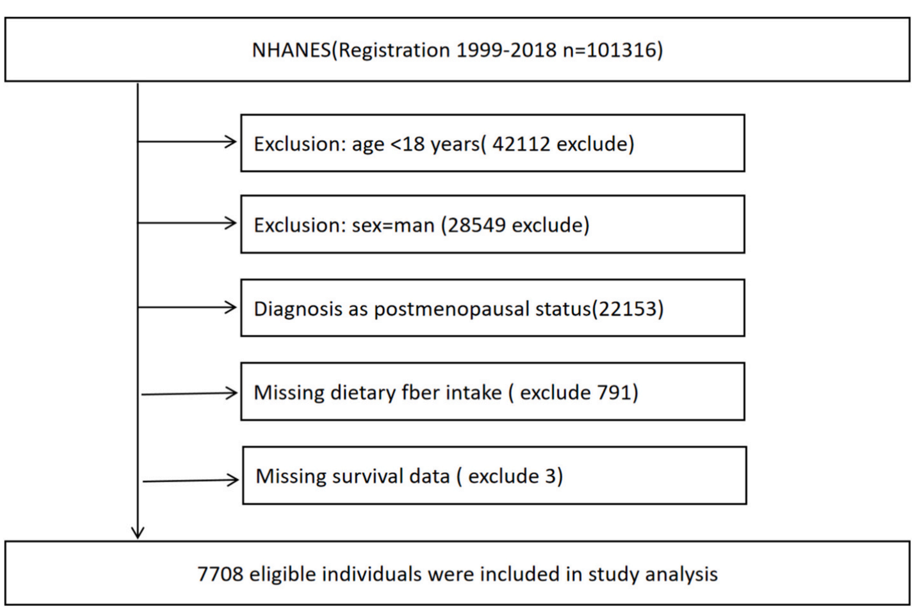

Fig. 1. Participant flowchart for postmenopausal women in NHANES 1999–2018 cohort.

any cause during the follow-up period. Mortality status and causes were ascertained via the National Death Index linkage, which provides information on death date and underlying cause of death (coded by ICD-10). We calculated person-time for each participant from baseline (NHANES exam date) to death or censoring.

The secondary outcome was cardiovascular disease (CVD) mortality, defined as any death for which the underlying cause was a cardiovascular condition. In ICD-10 coding, this corresponds to codes I00–I99 (encompassing ischemic heart disease, cerebrovascular disease, heart failure, and other circulatory causes).

2.4. Covariates

We included a range of covariates known or suspected to confound the relationship between diet (fiber) and mortality. Demographic factors: age (years, continuous), race/ethnicity (Non-Hispanic White, Non-Hispanic Black, Hispanic, Other), and educational attainment (less than high school, high school, some college or above) were included to account for baseline risk differences and socio-demographic influences on diet and mortality. We also included the poverty-to-income ratio (PIR), a measure of socio-economic status representing the ratio of household income to the federal poverty threshold (treated as a continuous variable), since socioeconomic status can influence diet quality and health outcomes.

Smoking status was categorized as current smoker, former smoker, or never smoker. Alcohol use was included as a covariate, defined in terms of current drinking status (yes/no) and frequency (we considered adjustment for heavy drinking, but the prevalence of heavy alcohol use in older women was low; thus we adjusted for current drinking vs. not). Physical activity was assessed via self-reported leisure-time activity; we calculated total physical activity in metabolic equivalent (MET)-minutes per week and included this as a continuous variable (log-transformed due to skewed distribution) to account for the beneficial effects of exercise on mortality risk. Body mass index (BMI) was calculated from measured height and weight (kg/mˆ2) and included as a continuous covariate, since BMI is related to both diet and mortality risk. Finally, we adjusted for sex (although the cohort was comprised of women, a small number of participants had missing or ambiguous sex data; including sex did not change results but we retained it for completeness in initial models).

2.5. Statistical analysis

We used multivariable Cox proportional hazards regression to estimate hazard ratios (HRs) and 95 % confidence intervals for the association between dietary fiber and mortality outcomes. Time-on-study (months) was the time scale. We verified that the proportional hazards assumption was met by examining Schoenfeld residuals and time-by-covariate interactions; no major violations were detected for the fiber variable or key covariates. For all-cause mortality, we fitted Cox models adjusting sequentially for: (1) age (basic adjustment); and (2) fully adjusted with all aforementioned covariates (age, race/ethnicity, education, PIR, smoking, alcohol, physical activity, BMI, sex). The primary results are from fully adjusted models. For CVD mortality, cause-specific Cox models (treating other causes of death as censored) were similarly fitted with the same covariates. We report HRs for fiber both as a continuous variable and comparing categories. To explore whether the association between fiber intake and mortality is linear or non-linear, we employed two approaches. The spline analysis suggested a non-linear relationship for all-cause mortality, with a steeper risk reduction at lower fiber intakes and a plateauing of the curve at higher intakes. We performed a piecewise (threshold) analysis **[8]** . We divided participants into tertiles of fiber intake: lowest tertile (T1, low intake), middle tertile (T2), and highest tertile (T3, high intake). Tertile cutpoints were ~ 9.7 g/day and ~ 17.6 g/day (these values partitioned the sample into three roughly equal groups). We estimated HRs for mortality for T2 and T3 using T1 (lowest fiber group) as the reference category. This categorical analysis provides an easily interpretable comparison of low vs. high fiber consumers and is less sensitive to extreme values or modeling assumptions. We conducted several sensitivity analyses to test the robustness of our results. We excluding participants who died in the first 2 years of follow-up, to mitigate potential reverse causation from subclinical illness affecting diet. The two-sided alpha level was set at 0.05. All the statistical analyses were performed using the EmpowerStats (www.empowerstats.com, X&Y solutions, Inc. Boston MA) and R software version 4.2.0 (http://www.r-project.org).

3. Results

3.1. Participant characteristics

A total of 7708 postmenopausal women were included at baseline (mean age 64.4 years, SD 11.3). The cohort included a broad age range from middle-aged to over 80. Approximately 20 % of participants were Non-Hispanic Black, 7 % Hispanic, with the remainder predominantly Non-Hispanic White and other ethnicities, reflecting the U.S. demographic composition. The median follow-up duration was 121 months (approximately 10 years). By the end of follow-up, 2116 women had died from all causes, representing 27.45 % of the cohort. Among these deaths, 657 (8.52 % of the cohort) were due to cardiovascular causes (heart disease, stroke, or other circulatory diseases), as shown in Table 1.

Baseline dietary fiber intake averaged 14.75 g/day (SD 7.5). As expected, high fiber consumers tended to have healthier lifestyle profiles: those in the highest fiber tertile were slightly younger (by ~2 years) and had lower BMI on average than those in the lowest tertile, as shown in Table 1.

3.2. Dietary fiber and all-cause mortality

We found a significant inverse association between dietary fiber intake and all-cause mortality. In the fully adjusted Cox model treating fiber as a continuous variable, the hazard ratio for all-cause mortality was 0.98 per 1 g/day increase in fiber (95 % CI 0.97–0.99, $p < 0.001$), indicating that higher fiber intake is associated with lower risk of death. However, this linear estimate averages the effect across the entire intake range. Inspection of the dose-response curve revealed non-linearity: the mortality risk dropped steeply with initial increases in fiber intake from very low levels, then leveled off at higher intake, as shown in **Fig. 2**.

3.3. Threshold effect at ~7.9 g/day

Using a piecewise analysis, we identified a notable change in slope around 7.9 g/day of fiber intake. When fiber intake was below this threshold, even small increases in fiber were linked to substantially lower mortality risk. Specifically, in women consuming <7.9 g of fiber per day (roughly the lowest quintile of intake), an increase of 5 g/day in fiber was associated with a 7 % reduction in all-cause mortality hazard (HR = 0.93 per +5 g, 95 % CI 0.89–0.97, $p = 0.0004$). For context, a 5 g/day increase is equivalent to adding roughly 1 apple plus 1 slice of whole-grain bread to one's daily diet.

In contrast, once fiber intake exceeded ~7.9 g/day, the additional benefit of further fiber increase was markedly attenuated. For women already consuming ≥7.9 g/day, an extra 5 g/day of fiber was associated with only a marginal reduction in all-cause mortality risk (HR = 0.99 per +5 g, 95 % CI 0.98–1.00, $p = 0.024$). This HR is very close to 1.00, implying almost no change in risk, albeit the confidence interval suggested a slight benefit that reached statistical significance. In practical terms, going from (for example) 15 g to 20 g/day of fiber was associated with only a tiny incremental mortality risk reduction in this cohort, as shown in Table 2.

These results indicate that the inverse association between fiber and

Table 1
Characteristics of postmenopausal women by fiber intake tertiles.

Characteristics	Total	Dietary fiber intake, g/day			*P*-value
		Tertile1 0.00–10.80	Tertile 2 10.85–16.50	Tertile 3 16.55–60.00	
Number	7708	2545	2589	2574	
Age (years)	64.36 ± 11.34	63.45 ± 12.01	65.13 ± 11.27	64.47 ± 10.65	<0.001
Body Mass Index(kg/m2)	29.75 ± 7.03	30.24 ± 7.39	29.90 ± 6.83	29.13 ± 6.84	<0.001
Poverty income ratio	2.57 ± 1.58	2.25 ± 1.52	2.60 ± 1.57	2.86 ± 1.61	<0.001
Dietary fiber intake, g	14.75 ± 7.46	7.67 ± 2.28	13.53 ± 1.63	22.98 ± 6.32	<0.001
Time (months)	123.35 ± 52.91	124.22 ± 55.32	121.97 ± 52.34	123.89 ± 50.99	0.415
Ethnicity					<0.001
Non-Hispanic White	4151 (53.85 %)	1285 (50.49 %)	1440 (55.62 %)	1426 (55.40 %)	
Non-Hispanic Black	1577 (20.46 %)	679 (26.68 %)	533 (20.59 %)	365 (14.18 %)	
Mexican American	1041 (13.51 %)	290 (11.39 %)	324 (12.51 %)	427 (16.59 %)	
Other Hispanic	570 (7.39 %)	186 (7.31 %)	182 (7.03 %)	202 (7.85 %)	
Other Race	369 (4.79 %)	105 (4.13 %)	110 (4.25 %)	154 (5.98 %)	
Education					<0.001
Below high school	1050 (13.62 %)	401 (15.76 %)	337 (13.02 %)	312 (12.12 %)	
High school	3160 (41.00 %)	1190 (46.76 %)	1092 (42.18 %)	878 (34.11 %)	
Above high school	3489 (45.26 %)	952 (37.41 %)	1159 (44.77 %)	1378 (53.54 %)	
Missing	9 (0.12 %)	2 (0.08 %)	1 (0.04 %)	6 (0.23 %)	
Poverty income ratio					<0.001
Poor	1243 (16.13 %)	549 (21.57 %)	375 (14.48 %)	319 (12.39 %)	
Nearly poor	2034 (26.39 %)	733 (28.80 %)	720 (27.81 %)	581 (22.57 %)	
Middle income	1996 (25.90 %)	621 (24.40 %)	689 (26.61 %)	686 (26.65 %)	
High income	1816 (23.56 %)	445 (17.49 %)	616 (23.79 %)	755 (29.33 %)	
Missing	619 (8.03 %)	197 (7.74 %)	189 (7.30 %)	233 (9.05 %)	
Smoking status					<0.001
Never	4483 (58.16 %)	1323 (51.98 %)	1544 (59.64 %)	1616 (62.78 %)	
Former	2101 (27.26 %)	662 (26.01 %)	706 (27.27 %)	733 (28.48 %)	
Now	1118 (14.50 %)	558 (21.93 %)	337 (13.02 %)	223 (8.66 %)	
Missing	6 (0.08 %)	2 (0.08 %)	2 (0.08 %)	2 (0.08 %)	
Alcohol use					<0.001
Never	1818 (23.59 %)	633 (24.87 %)	599 (23.14 %)	586 (22.77 %)	
Former	1960 (25.43 %)	714 (28.06 %)	686 (26.50 %)	560 (21.76 %)	
Mild	2352 (30.51 %)	632 (24.83 %)	782 (30.20 %)	938 (36.44 %)	
Moderate	997 (12.93 %)	320 (12.57 %)	350 (13.52 %)	327 (12.70 %)	
Heavy	565 (7.33 %)	238 (9.35 %)	166 (6.41 %)	161 (6.25 %)	
Missing	16 (0.21 %)	8 (0.31 %)	6 (0.23 %)	2 (0.08 %)	
Total physical activity(MET/week)					<0.001
<600	1957 (25.39 %)	608 (23.89 %)	671 (25.92 %)	678 (26.34 %)	
≥ 600	2749 (35.66 %)	756 (29.71 %)	913 (35.26 %)	1080 (41.96 %)	
Missing	3002 (38.95 %)	1181 (46.40 %)	1005 (38.82 %)	816 (31.70 %)	
Marital status					<0.001
Married/Living with Partner	3865 (50.18 %)	1214 (47.76 %)	1274 (49.21 %)	1377 (53.54 %)	
Widowed/Divorced/Separated	3378 (43.85 %)	1172 (46.11 %)	1160 (44.80 %)	1046 (40.67 %)	
Never married	460 (5.97 %)	156 (6.14 %)	155 (5.99 %)	149 (5.79 %)	
Coronary Heart Disease					0.04
No	7289 (95.16 %)	2384 (94.38 %)	2447 (95.18 %)	2458 (95.90 %)	
Yes	371 (4.84 %)	142 (5.62 %)	124 (4.82 %)	105 (4.10 %)	
Congestive Heart Failure					<0.001
No	7302 (95.05 %)	2381 (93.96 %)	2438 (94.39 %)	2483 (96.80 %)	
Yes	380 (4.95 %)	153 (6.04 %)	145 (5.61 %)	82 (3.20 %)	
Myocardial Infarction					<0.001
No	7276 (94.55 %)	2344 (92.36 %)	2447 (94.62 %)	2485 (96.65 %)	
Yes	419 (5.45 %)	194 (7.64 %)	139 (5.38 %)	86 (3.35 %)	
All-cause mortality					<0.001
survival	5592 (72.55 %)	1750 (68.76 %)	1842 (71.15 %)	2000 (77.70 %)	
non-survival	2116 (27.45 %)	795 (31.24 %)	747 (28.85 %)	574 (22.30 %)	
Cardiovascular mortality					<0.001
survival	7051 (91.48 %)	2283 (89.71 %)	2351 (90.81 %)	2417 (93.90 %)	
non-survival	657 (8.52 %)	262 (10.29 %)	238 (9.19 %)	157 (6.10 %)	

Continuous variables: mean ± SD (ANOVA); categorical variables: n (%) (χ^2 test). MET: metabolic equivalent of task.

mortality was much stronger at the lower end of fiber consumption. Once a moderate intake level was achieved, further increases in fiber did not substantially improve survival in this population during the follow-up period.

3.4. High vs. low fiber intake (Tertile analysis)

To contextualize the findings, we compared mortality outcomes between participants with high fiber diets and those with low fiber diets. Fig. 3 would depict Kaplan-Meier survival curves by fiber tertiles, which separated over time with the high-fiber group experiencing the highest survival probability.

In multivariable Cox models, women in the highest fiber intake tertile had significantly lower mortality risk than those in the lowest tertile. The HR for all-cause mortality comparing highest vs. lowest tertile was 0.85 (95 % CI 0.76–0.95, $p = 0.0057$) after full adjustment, as shown in Table 3.

The protective association was even more pronounced for cardiovascular mortality. The highest fiber tertile had a 31 % lower risk of CVD death compared to the lowest tertile (HR = 0.69, 95 % CI 0.56–0.86, $p =$

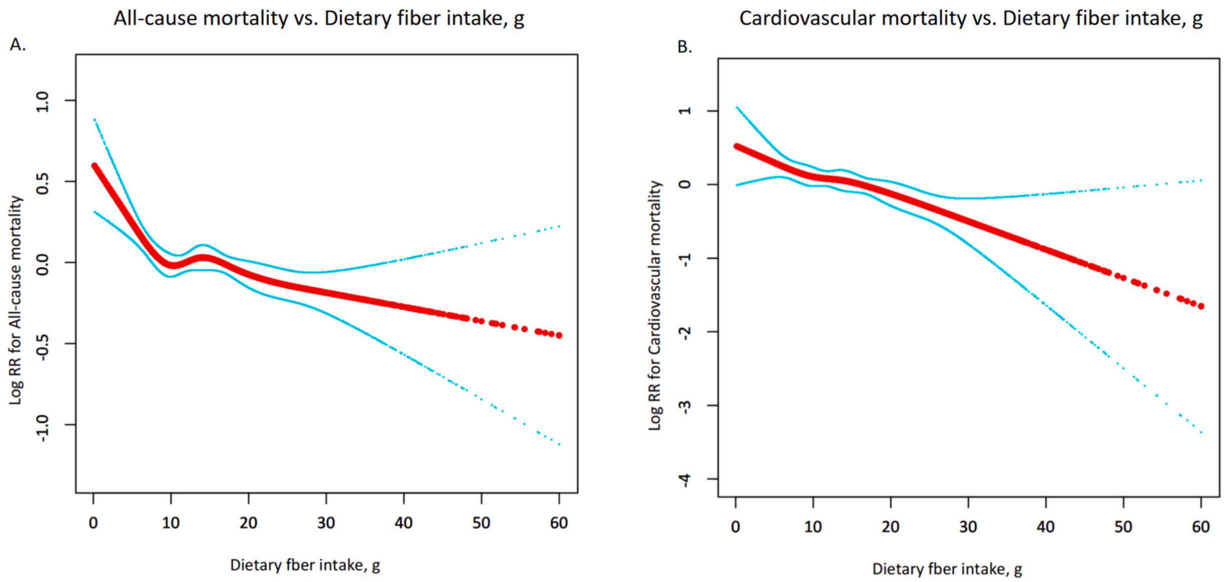

Fig. 2. Dose-response relationship between fiber intake and mortality risk. Non-linear association of fiber intake with all-cause mortality (restricted cubic spline). Red line indicates adjusted hazard ratio; green area: 95 % confidence interval. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Threshold effects of fiber intake (per 5 g increase) on all-cause and CVD mortality.

Models	All-cause mortality		Cardiovascular mortality	
	Per 5 g increase		Per 5 g increase	
	HR(95 %CI)	*P* value	HR(95 %CI)	*P* value
Model I				
One lines effect	0.93 (0.90, 0.97)	<0.0001	0.87 (0.81, 0.93)	<0.0001
Model II				
Turning point(K)	7.9		17.15	
Dietary fiber intake<K	0.69 (0.56, 0.85)	0.0004	0.90 (0.80, 1.00)	0.0523
Dietary fiber intake≥K	0.96 (0.92, 0.99)	0.0246	0.82 (0.70, 0.96)	0.0109
P value for LRT TEST*		0.005		0.421

Thresholds determined by segmented regression. Models adjusted for age (years), sex, ethnicity, education, poverty income ratio, smoking status, alcohol use, total physical activity (MET/week), body mass index(kg/m2). HR: hazard ratio; CVD: cardiovascular disease.

0.0007). In fully adjusted terms, this suggests that diets rich in fiber were strongly linked to cardiovascular survival benefits, as shown in Table 3. CVD mortality rates were notably lower among high-fiber consumers; for instance, the 10-year CVD death rate in the lowest fiber group was roughly 10 %, versus about 7 % in the highest fiber group.

3.5. Additional analyses and sensitivity checks

We performed stratified analyses to see if the fiber-mortality association differed across subgroups. The inverse association between fiber and all-cause mortality was present (though with varying magnitude) in virtually all subgroups examined, including younger vs. older seniors, different ethnic groups, obese vs. non-obese individuals, and those with vs. without baseline diabetes or hypertension (interaction *p*-values were not significant for these factors). This suggests the protective effect of fiber is relatively consistent across diverse subsets of postmenopausal women (Table S1).

4. Discussion

In this large nationally representative cohort of U.S. postmenopausal women, we found that dietary fiber intake was inversely associated with long-term mortality. Women who consumed more fiber had a lower risk of dying from all causes, and especially from cardiovascular causes, over ~10 years of follow-up. Those in the highest third of fiber intake had about 15 % lower all-cause mortality and 31 % lower CVD mortality compared to those with the lowest fiber intake. These findings reinforce and extend the evidence from previous studies that fiber-rich diets confer longevity benefits.

Our results are consistent with prior research demonstrating fiber's protective role in mortality. A 2024 systematic review and meta-analysis by Ramezani et al. reported that diets high in fiber were associated with a 23 % reduction in all-cause mortality risk and a 26 % reduction in CVD mortality risk, compared to low-fiber diets, across multiple cohorts and populations (64 studies) [2]. The magnitude of effect we observed (highest vs lowest tertile HR ~0.85 for all-cause mortality) is slightly more modest, likely because our analysis is confined to an older female demographic with generally lower fiber variance. Nonetheless, the direction and general size of the association align well with the meta-analytic evidence. It also aligns with earlier landmark cohort studies: for example, Park et al. (2011) found in the NIH-AARP Diet and Health Study (which included older adults) that participants in the highest fiber quintile had ~22 % lower risk of total death than those in the lowest quintile [6]. Park and colleagues additionally observed significant reductions in CVD, infectious, and respiratory disease mortality associated with higher fiber intake, suggesting broad health benefits of fiber [6]. Our analysis in postmenopausal women similarly indicates that fiber's benefit is not limited to one specific cause of death (we saw strong effects on CVD mortality and a trend toward lower cancer and other mortality as well).

One interesting aspect of our findings is the non-linear (threshold) relationship between fiber intake and mortality. We found that most of fiber's mortality benefit was realized at relatively low levels of intake (~8–10 g/day), with diminishing returns thereafter. This might seem surprising given public health recommendations encourage much higher fiber consumption (e.g., 21–25 g/day for women) [3]. However, our finding does not imply that 8 g/day is "enough" for optimal health. Rather, it suggests that the contrast between extremely low fiber intake

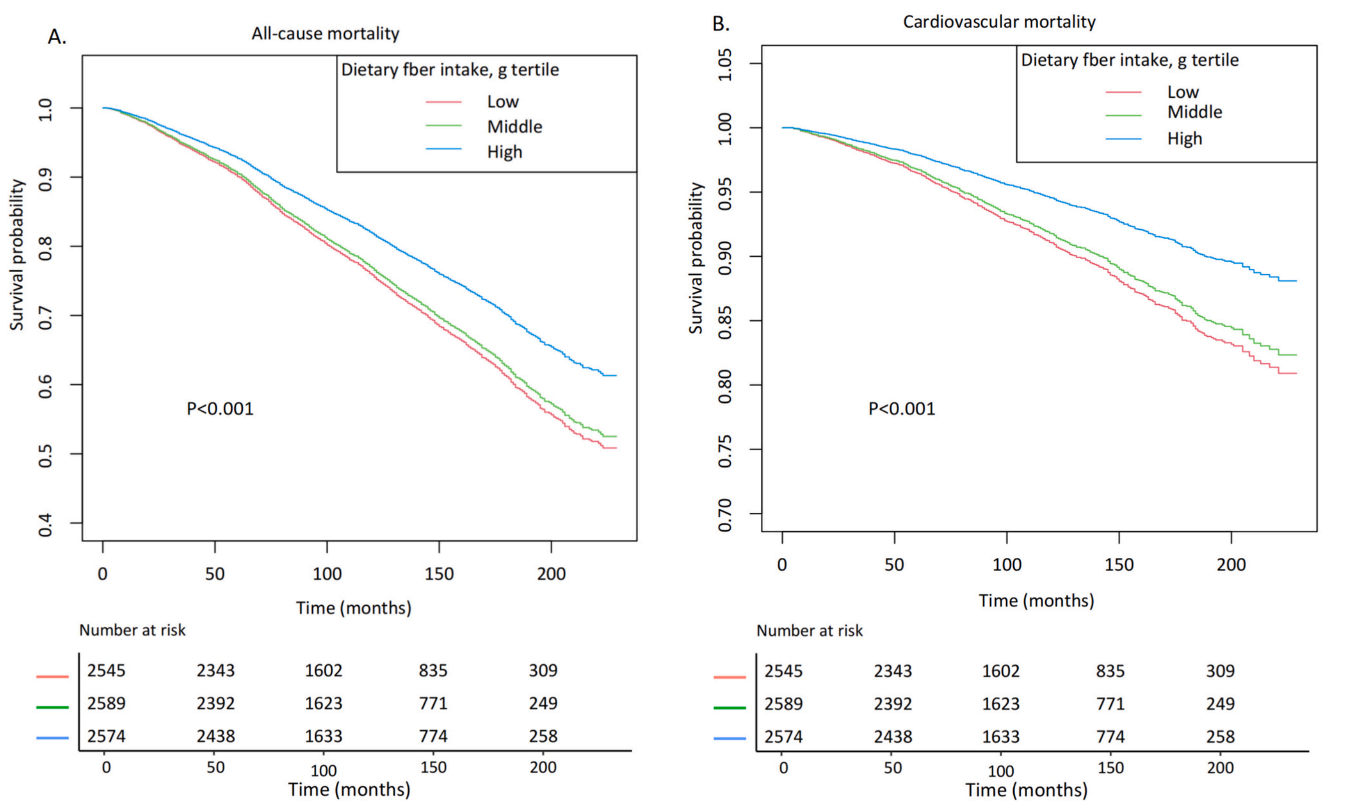

Fig. 3. Kaplan-Meier Survival Curves by Dietary Fiber Tertiles in Postmenopausal Women (NHANES 1999–2018). All-cause mortality risk stratified by fiber intake tertiles (low: <10.8 g/day, middle: 10.8–16.5 g/day, high: >16.5 g/day). Log-rank test $p < 0.001$.

Table 3
Hazard ratios for all-cause and cardiovascular mortality by fiber intake.

Outcome	All-cause mortality			
Exposure	Adjust I HR(95 %CI)	*P* value	Adjust II HR(95 %CI)	*P* value
Dietary fiber intake, per 5 g increase	0.91 (0.88, 0.94)	<0.0001	0.93 (0.90, 0.97)	<0.0001
Dietary fiber intake, g tertile				
Low	Ref		Ref	
Middle	0.92 (0.83, 1.02)	0.1109	0.94 (0.85, 1.05)	0.265
High	0.78 (0.70, 0.88)	<0.0001	0.85 (0.76, 0.95)	0.0057
P for trend		<0.0001		0.006
Outcome	Cardiovascular mortality			
Exposure	Adjust I HR(95 %CI)	*P* value	Adjust II HR(95 %CI)	*P* value
Dietary fiber intake, per 5 g increase	0.84 (0.79, 0.90)	<0.0001	0.87 (0.81, 0.93)	<0.0001
Dietary fiber intake, g tertile				
Low	Ref		Ref	
Middle	0.86 (0.72, 1.02)	0.0884	0.86 (0.72, 1.04)	0.1152
High	0.63 (0.52, 0.78)	<0.0001	0.69 (0.56, 0.86)	0.0007
P for trend		<0.0001		0.0007

Statistical tests: Likelihood ratio test (LRT) for non-linearity (p = 0.005 for all-cause mortality). Adjust I model adjust for: age (years); sex; ethnicity; education; poverty income ratio; smoking status. Adjust II model adjust for: age (years), sex, ethnicity, education, poverty income ratio, smoking status, alcohol use, total physical activity(MET/week), body mass index(kg/m2). HR: hazard ratio; CVD: cardiovascular disease.

and moderate intake is where the mortality risk difference is largest in this cohort. Women with very low fiber intake (<8 g/day) likely have diets severely lacking in fruits, vegetables, and whole grains – these diets may be high in refined carbohydrates and fats and low in micronutrients, which could lead to greater health risks. Once a person includes at least a modest amount of fiber-containing foods (e.g., a few servings of produce or whole grains reaching ~15 g/day of fiber), the incremental benefit of adding yet more fiber may be smaller in the short-to-medium term.

In the context of other studies, some have reported a more linear dose-response or benefits continuing at higher fiber doses. Notably, a 2023 dose–response meta-analysis by Yao et al. found a non-linear association where risk of all-cause mortality kept improving up to about 25–30 g of fiber per day, with a plateau beyond that [9]. They observed that mortality risk reduction was greatest when fiber intake was ~25–29 g/day, and there were additional albeit smaller benefits even beyond 30 g/day. Why do our results suggest a much lower threshold (~8 g) for plateauing benefit? One likely reason is the range of intake and reference group differences. Our cohort's intake was largely low; very few women consumed above 30 g, so our ability to detect benefits at that high end was limited. Essentially, our "high fiber" group is around 20 g/day on average – which is still below the recommended amount. In Yao et al.'s global meta-analysis, some cohorts included people eating >40 g/day (e.g., high-fiber vegetarian diets), allowing them to discern benefits at higher levels that we could not observe due to lack of such participants in NHANES. Additionally, the steep drop in risk from 0 to 8 g in our data may reflect the particularly detrimental effects of extremely low fiber intake (which in Western populations can correlate with diets high in ultra-processed foods). In practical terms, going from a very fiber-poor diet to a somewhat fiber-inclusive diet yields a big health improvement, whereas going from a moderate to a high fiber diet yields a subtler improvement – at least within a decade of follow-up.

It's also worth considering that fiber intake might be a marker of overall diet quality and healthy lifestyle. We adjusted for many such factors (fruits/vegetable intake is inherently captured by fiber intake to some extent, and we adjusted for physical activity, smoking, etc.), but residual confounding could still influence the shape of the association. For example, those consuming extremely low fiber might have other unmeasured risk factors (like poor overall nutrition or economic hardship affecting diet) that elevate their mortality risk [10]. Conversely, extremely high fiber consumers might have other health-promoting behaviors that we could not fully adjust for [11]. Nonetheless, given consistency with controlled metabolic studies on fiber's effects, it is plausible that the relationship is truly non-linear biologically – initial fiber intake confers essential benefits (like improved gut function and cardiometabolic parameters) that prevent disease, while additional fiber beyond a point yields smaller incremental physiological changes [12,13].

There are several biologically plausible mechanisms through which higher dietary fiber intake can lead to lower mortality risk, particularly by reducing chronic disease incidence and progression [9]. Cardiovascular pathways are paramount: Diets rich in fiber, especially soluble fiber, have been shown to lower serum cholesterol levels and improve lipid profiles, thereby reducing atherogenic risk [14]. Fiber can bind bile acids and cholesterol in the gut, leading to increased excretion of cholesterol and lower LDL levels [15]. In our study, the pronounced reduction in CVD mortality among high fiber consumers (31 % lower) is consistent with these cardioprotective effects [14]. Fiber also modulates postprandial glucose and insulin responses, improving insulin sensitivity [16]. By slowing carbohydrate absorption, fiber helps maintain better glycemic control [17]. This can reduce the risk of type 2 diabetes and metabolic syndrome, conditions which significantly contribute to mortality [18]. Improved insulin sensitivity and lower insulin levels may also inhibit pathways of inflammation and cellular proliferation that underlie diseases like cancer [19]Another key mechanism is through blood pressure reduction: High-fiber diets, particularly those abundant in fruits, vegetables, and whole grains (sources of potassium and magnesium), are associated with lower blood pressure. Lower blood pressure reduces stroke and heart disease risk, translating to fewer cardiovascular deaths [14].Perhaps one of the most intriguing areas of research is fiber's effect on the gut microbiota and inflammation. Dietary fibers, especially fermentable soluble fibers, serve as substrates for the gut bacteria, leading to the production of short-chain fatty acids (SCFAs) such as butyrate [20]. SCFAs have multiple beneficial systemic effects: they improve colonic health, enhance immune regulation, and have anti-inflammatory properties [21]. High fiber intake has been linked to lower levels of systemic inflammation (e.g., reduced C-reactive protein and cytokines) [22]. Chronic inflammation is a known driver of many age-related diseases (atherosclerosis, cancer, etc.) [23]. By mitigating inflammation, fiber could thereby lower the risk of both cardiovascular events and certain cancers. The NIH-AARP study by Park et al. found fiber was associated with significantly lower infectious and respiratory disease mortality as well, which might be explained by fiber's role in supporting immune function and lung health (possibly through anti-inflammatory effects and fermentation byproducts that influence immunity) [6]. Moreover, fiber contributes to better weight management through increased satiety and reduced overall calorie intake [24]. Participants with higher fiber intakes in our study had slightly lower BMI on average. Adequate fiber can help prevent obesity, which is a risk factor for many causes of death. By promoting a healthier body weight, fiber indirectly lowers mortality risk [2]. Finally, fiber from various sources may have specific benefits. For example, cereal fiber (from whole grains) has consistently been associated with lower mortality in multiple studies potentially because it coexists with other nutrients like vitamins, minerals, and antioxidants in whole grains [2]. While our analysis did not differentiate fiber types, the general advice is that obtaining fiber from a variety of foods – grains, fruits, vegetables, legumes, nuts – provides a broad spectrum of nutrients and phytochemicals that collectively contribute to health. Some of the protective effect we observe for fiber could in part reflect these co-nutrients. However, the fact that fiber per se shows strong associations even after adjusting for other dietary factors suggests that fiber is not merely a marker of a healthy diet but an active contributor to health outcomes [9].

Our findings hold practical significance for public health and dietary guidance, especially for older women. Despite slightly diminishing returns at higher intake, the overarching message is that increasing dietary fiber intake is beneficial for longevity and cardiovascular health. Many postmenopausal women in the U.S. do not consume even close to the recommended amount of fiber [25]. As our results indicate, women with extremely low fiber intake experience the highest mortality rates. Encouraging those individuals to raise their fiber consumption – even by modest amounts like an extra 5–10 g per day – could yield meaningful improvements in survival. This could be achieved through simple dietary shifts, such as replacing refined grains with whole grains, adding an extra serving of vegetables to meals, or snacking on fiber-rich fruits or nuts. Importantly, our data suggest that one doesn't necessarily need to reach very high fiber intake (e.g., >30 g/day) to derive substantial benefit; moving out of the lowest intake category is the most critical step. This is encouraging from a behavioral standpoint, as recommending achievable incremental changes (like "add a cup of beans or a salad each day") may be more attainable for individuals than striving for an ideal of 25+ grams if they currently eat very little fiber. That said, for the broader population and over a longer term, aiming for the recommended 21–25 g/day for women (and ~ 30 g for men) remains a prudent goal [3]. Such levels are associated with multiple health benefits and likely would show greater mortality benefit if observed for longer follow-up and in combination with an overall healthy lifestyle. Our results also underscore the particular importance of fiber for cardiovascular health in older women. Postmenopausal women face rising CVD risk due to loss of estrogen's protective effects and the accumulation of risk factors with age. Fiber's association with a one-third reduction in CVD mortality highlights it as a potentially powerful dietary factor for CVD prevention [26]. This aligns with dietary patterns known to reduce CVD risk (DASH, Mediterranean diet, etc.), which are all naturally high in fiber. Thus, promoting fiber intake should be a component of cardiovascular risk reduction strategies in this demographic [27].

Key strengths of this study include the use of a large sample with standardized data collection and robust follow-up for mortality. The NHANES data allowed us to adjust for a wide array of confounders and lifestyle factors, strengthening the causal inference that fiber itself plays a role in mortality risk. Our analysis specifically focused on postmenopausal women, providing insights for a group in which diet-disease relationships are sometimes understudied or assumed from mixed-sex studies. We were able to investigate dose-response patterns in detail and identify a potential threshold effect, which adds nuance to the understanding of how fiber intake translates into health benefits. Additionally, linking multiple NHANES cycles gave us sufficient events and power to detect associations in subgroup and sensitivity analyses, lending confidence to the robustness of our findings. This study is observational, and as such we cannot definitively establish causality. Although we controlled for many confounders, unmeasured or residual confounding is possible – for example, we did not explicitly adjust for overall diet quality or intake of other specific nutrients (aside from the inherent correlation that exists with fiber intake) [28]. It is possible that fiber intake serves as a proxy for a generally healthy diet rich in plant foods and that some of the mortality benefit is due to other constituents of those foods (vitamins, polyphenols, etc.) [6]. However, given the wealth of mechanistic evidence on fiber's direct effects, we believe fiber itself is a major contributor to the observed associations. Dietary intake was measured via a single 24-h recall at baseline, which may not perfectly reflect habitual intake. Measurement error in diet assessment could attenuate true associations [29]. If some women were misclassified in terms of their usual fiber consumption, our risk estimates might be conservative. Repeated dietary measures over time would be ideal but were not available. Moreover, changes in diet during follow-up were not accounted for – if some participants improved or worsened their diet after baseline, our analysis would not capture that dynamic, possibly underestimating associations [30]. We observed a mortality benefit associated with fiber within ~10 years of follow-up. It's worth noting that dietary effects on mortality might accrue over longer periods; thus, a longer follow-up might reveal stronger associations or benefits of higher fiber intakes [6]. Our cohort had a relatively high mortality rate given the age group, which is expected, but also means competing risks from various causes could complicate interpretation of cause-specific mortality beyond CVD (we had limited power for non-CVD causes).There may also be survivor bias – women who lived long enough to participate in NHANES (especially in older age groups) might already be a somewhat healthier subset, potentially attenuating dietary effects. However, within our sample, fiber still distinguished mortality outcomes [31].

Lastly, while our focus on postmenopausal women is a strength for specificity, it limits generalizability. These results may not directly extrapolate to men or to younger women. Men, who generally consume more fiber, might have a different dose-response curve, and premenopausal women might have different sensitivities to dietary factors. Nonetheless, broad evidence suggests fiber is beneficial across sexes and ages, so the main message likely holds: more fiber is better, particularly when starting from a low intake.

5. Conclusions

In conclusion, our study provides strong evidence that greater dietary fiber intake is associated with lower all-cause and cardiovascular mortality in postmenopausal women. Even moderate increases in fiber consumption – for example, shifting from a very low fiber diet to an intake of around 15–20 g per day – were linked to significant improvements in survival. These findings support current dietary recommendations and public health efforts to increase fiber intake in the population. For clinicians and health educators, emphasizing fiber-rich foods (such as fruits, vegetables, whole grains, legumes, and nuts) to older women could be a key nutritional strategy to enhance longevity and reduce the burden of cardiovascular disease. Future research should explore interventions to effectively raise fiber intake in this demographic and examine whether particular sources of fiber or timing of intake (earlier in life vs. later) further modify long-term outcomes. Additionally, investigating the interplay between fiber and the gut microbiome in relation to aging and immunity may shed light on the pathways through which a high-fiber diet contributes to a longer and healthier life. In the meantime, our findings add to a consistent body of literature: a fiber-rich diet is a cornerstone of healthy aging, and even small steps toward higher fiber intake can translate into meaningful gains in survival for older adults.

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CRediT authorship contribution statement

Yafei Guo participated in data collection, data cleaning, statistical analysis, preparation of figures and tables, and drafting and editing of the paper.

Meiling Li participated in auditing the data analyses and critical revision of the manuscript.

Weihuang Zhuang participated in study conception and design, interpretation of data, and critical revision of the manuscript.

All authors saw and approved the final version and no other person made a substantial contribution to the paper.

Ethical approval

The NHANES study protocol was approved by the National Center for Health Statistics (NCHS) Ethics Review Board (Protocol No.: 2011–17) and adheres to U.S. Department of Health and Human Services human subject protection policies. Ethical approval was not required for this analysis as it utilized de-identified, publicly available NHANES data. All participants in the NHANES study provided informed consent.

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Declaration of competing interest

The authors declare that they have no competing interest.

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Data availability

The data used in this study are publicly available from the NHANES database (https://wwwn.cdc.gov/nchs/nhanes/default.aspx) and the National Death Index (https://www.cdc.gov/nchs/data-linkage/mortality-public.htm).

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