CLINICAL RESEARCH STUDY

Dietary Fiber Intake and Cardiometabolic Risks among US Adults, NHANES 1999-2010

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ABSTRACT

BACKGROUND: Dietary fiber may decrease the risk of cardiovascular disease and associated risk factors. We examined trends in dietary fiber intake among diverse US adults between 1999 and 2010, and investigated associations between dietary fiber intake and cardiometabolic risks including metabolic syndrome, cardiovascular inflammation, and obesity.

METHODS: Our cross-sectional analysis included 23,168 men and nonpregnant women aged 20+ years from the 1999-2010 National Health and Nutrition Examination Survey. We used weighted multivariable logistic regression models to estimate predicted marginal risk ratios and 95% confidence intervals for the risks of having the metabolic syndrome, inflammation, and obesity associated with quintiles of dietary fiber intake.

RESULTS: Consistently, dietary fiber intake remained below recommended adequate intake levels for total fiber defined by the Institute of Medicine. Mean dietary fiber intake averaged 15.7-17.0 g. Mexican Americans (18.8 g) consumed more fiber than non-Hispanic whites (16.3 g) and non-Hispanic blacks (13.1 g). Comparing the highest with the lowest quintiles of dietary fiber intake, adjusted predicted marginal risk ratios (95% confidence interval) for the metabolic syndrome, inflammation, and obesity were 0.78 (0.69-0.88), 0.66 (0.61-0.72), and 0.77 (0.71-0.84), respectively. Dietary fiber was associated with lower levels of inflammation within each racial and ethnic group, although statistically significant associations between dietary fiber and either obesity or metabolic syndrome were seen only among whites.

CONCLUSIONS: Low dietary fiber intake from 1999-2010 in the US, and associations between higher dietary fiber and a lower prevalence of cardiometabolic risks suggest the need to develop new strategies and policies to increase dietary fiber intake.

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KEYWORDS: Dietary fiber; Disparities; Metabolic diseases; NHANES

The benefits of dietary fiber on cardiovascular risk reduction have been documented.[1-4] Specifically, epidemiologic data suggest a protective relationship between dietary fiber

and risk factors for cardiovascular disease, including components of the metabolic syndrome,[5,6] and related risks such as cardiovascular inflammation.[7,8] Dietary fiber intake is thought to play a role in cardiometabolic and cardiovascular disease risk reduction by decreasing blood pressure,[9] cholesterol levels,[10,11] and levels of biomarkers of inflammation.[8,12] Additionally, fiber intake is associated with an increased sensation of satiety thought to contribute to weight loss,[9] and improved insulin sensitivity.[13,14] Based on large-scale prospective cohort studies and small-scale intervention studies that show reductions in coronary heart disease risk, including lipid reduction associated with dietary and functional fiber intake from oat cereal and bean sources, the Institute of Medicine has established a

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recommended "adequate intake" level for total fiber intake by age and sex: 38 g per day for men aged 19-50 years, 30 g per day for men older than 50 years, 25 g per day for women aged 19-50 years, and 21 g per day for women older than 50 years.[15] To date, recent studies have not fully investigated potential demographic and socioeconomic disparities in dietary fiber intake over time, or the relation between dietary fiber intake and cardiometabolic risk factors in diverse populations. Surveillance data from the National Health and Nutrition Examination Survey (NHANES) can assist in identifying vulnerable groups that may benefit from targeted dietary interventions, and help estimate cardiometabolic risks associated with dietary fiber intake in diverse groups.[16]

The present study has 3 objectives: to examine secular trends in dietary fiber intake among US adults from 1999 to 2010; to investigate possible sex, age, racial/ethnic, and socioeconomic disparities in dietary fiber intake trends during this time period; and to examine the association between dietary fiber intake and the prevalence of cardiometabolic risk factors, the metabolic syndrome, inflammation, and obesity in diverse groups of adults in the US, with attention to any racial/ethnic differences in associations between fiber intake and cardiometabolic risks.

METHODS

Study Population
Our study examines data from the 1999-2010 NHANES. The NHANES is a cross-sectional, nationally representative sample of the US noninstitutionalized civilian population.[17] The NHANES population was recruited using a multistage, stratified sampling design.[17] Our study population included all nonpregnant participants, aged 20 years and older in the 1999 to 2010 NHANES cohorts (n = 30,433). Those with complete data for all covariates including dietary fiber intake, C-reactive protein (CRP), and body mass index were included in the analysis of inflammation and obesity (n = 23,168). Individuals who did not participate in the fasting subsample were excluded from the analysis of the metabolic syndrome (n = 12,374). After limiting the cohort to participants with complete data for all covariates, there were 10,473 people included in the analysis of the metabolic syndrome. Human subject procedures for NHANES were approved by the National Center for Health Statistics Research Ethics Review Board. Our study was approved by the Partners Institutional Review Board.

CLINICAL SIGNIFICANCE

- Consistently, dietary fiber intake has been below recommended adequate intake levels for all US adults from 1999 to 2010.

- Lower dietary fiber intake is found to be associated with a higher prevalence of cardiometabolic risks including metabolic syndrome, cardiovascular inflammation, and obesity among US adults.

- Additional clinical and population-based strategies may be needed to increase recommended adequate fiber intake for US adults.

Dietary Fiber Intake
Dietary intake data were assessed using 24-hour dietary recalls, administered during computer-assisted, in-person interviews by a trained interviewer at NHANES Mobile Examination Centers. Nutrient intakes were coded and analyzed using the United States Department of Agriculture (USDA) 1994-98 Survey Nutrient Database (1999-2001) and the USDA Food and Nutrient Databases for Dietary Studies (2001-2010).[6,17-19] From 1999-2002, NHANES assessed dietary intake with one 24-hour recall date. Beginning in 2003, NHANES collected 2 24-hour dietary recalls for each participant. To facilitate comparability across all 12 survey years, our analysis used dietary intake data from the first 24-hour recall interview.

Clinical Outcomes
According to Adult Treatment Panel III criteria, we classified individuals with at least 3 of the following cardiometabolic components as having the metabolic syndrome:

- abdominal obesity (waist circumference >102 cm in males and >88 cm in females);
- elevated blood pressure (≥130/85 mm Hg);
- hypertriglyceridemia (≥150 mg/dL);
- low high-density lipoprotein (HDL) cholesterol (<40 mg/dL in males and <50 mg/dL in females); and
- elevated fasting plasma glucose (≥100 mg/dL).[20,21]

We classified individuals with a CRP concentration >3.0 mg/L as having elevated CRP.[22,23] We defined obesity as having a body mass index ≥30.0 kg/m^2.[24]

Analytes were collected via venipuncture from fasting blood samples at the NHANES Mobile Examination Center. HDL cholesterol was measured by the heparin-manganese precipitation method (1999-2002) and the direct HDL cholesterol immunoassay method (2003-2010); we used the adjusted HDL measurements as reported by NHANES for the years that required correction due to assay-related bias.[25] Across all 12 survey years, plasma glucose was determined using the hexokinase enzymatic assay. Fasting plasma glucose levels were determined only for those subjects who participated in the morning fast. In 1999-2010, CRP concentrations were measured by high-sensitivity latex-enhanced nephelometry.

Blood pressure, waist circumference, and body mass index were measured at the Mobile Examination Center. Detailed descriptions about blood collection and processing and anthropometric measurements have been described.[26]

Demographic and Other Behavioral Characteristics

The primary covariates included in this analysis were: age (20-50 years, ages 51 years and older), sex, race/ethnicity (Mexican American, non-Hispanic white, non-Hispanic black), educational attainment (<9th grade, 9-12th grade and no diploma, high school diploma or General Educational Development test, associate's degree or some college, bachelor's degree or higher), smoking status (current smoker: ≥100 cigarettes in life and currently smoking; former smoker; never smoker: <100 cigarettes in life), and total energy intake (low: males <2000 kcal/day, females <1600 kcal/day; adequate: males 2000-3000 kcal/day, females 1600-2400 kcal/day; high: males >3000 kcal/day, females >2400 kcal/day).[27]

Statistical Analysis

Temporal trends in dietary fiber intake between 1999 and 2010 were estimated using weighted linear regression in SUDAAN (version 9.0.1; RTI International, Research Triangle Institute, Research Triangle Park, NC) to account for the complex sampling design. These temporal trends were estimated for the entire cohort and within categories for age, sex, racial/ethnicity, and educational attainment. Multivariable models were used to examine the association between quintiles of dietary fiber intake and cardiometabolic risks, while also adjusting for potential confounding factors. We used weighted multivariable logistic regression models to estimate the predicted marginal risk ratios (RR) and 95% confidence intervals (CI) for the risk of having the metabolic syndrome, inflammation, and obesity associated with quintiles of dietary fiber intake.[28] Models adjusted for age and total energy intake were compared with fully adjusted models with the following covariates: age, sex, race/ethnicity, educational attainment, smoking status, and total energy intake.[29,30] Accounting for the complex sampling design in NHANES, all statistical analyses were conducted in an SAS-callable version of SUDAAN. Twelve-year fasting subsample weights were used for the analysis of the metabolic syndrome (n = 10,473) and 12-year Mobile Examination Center weights were used for the analysis of inflammation and obesity (n = 23,168). Statistical significance was based on 2-tailed tests of statistical significance at an alpha level of .05.

A sensitivity analysis was performed to exclude outlier values with low and high dietary fiber intakes below the 5th and 1st percentile and above the 95th and 99th percentile ranges to determine their influence on the associations we report. Additionally, the recall period and the domains classifying physical activity substantially changed between survey cycles 2005-2006 and 2007-2008, limiting the ability to make direct comparisons across all years.[31] We also conducted sensitivity analyses to estimate potential confounding effects of physical activity on the associations we report, and we estimated associations adjusted for physical activity measures separately in the 1999-2006 and 2007-2010 cohorts. Categories of physical activity (no activity; some/irregular activity; regular activity) were based on the US Department of Health and Human Services 2008 Physical Activity Guidelines for Americans.[32] These results are available in a supplemental appendix (Appendices 1, 2, online).

RESULTS

Study Population Characteristics

Study population characteristics are listed in Table 1 by mean dietary fiber intake. Reported dietary fiber intake among all nonpregnant adults ranged between 6.3 grams per day (g/d) (10th percentile) and 29.0 g/d (90th percentile). Mean dietary fiber intake was 16.2 g/d (Table 1). In comparison with those who consumed lower amounts of dietary fiber, participants who consumed higher amounts of dietary fiber were more likely to be older (51 years and older), male, Mexican-American, highly educated (bachelor's degree or greater), former smokers, and physically active.

Trends in Dietary Fiber

Figure 1 presents the trends in crude mean dietary fiber intake among nonpregnant US adults and crude mean dietary fiber intake by sex, age, educational attainment, and race/ethnicity across 12 survey years. The daily crude fiber intake among all US adults increased by approximately 1.3 g between 1999 and 2010. However, quantities of dietary fiber intake among US adults were below total recommended adequate intake levels, as recommended by the Institute of Medicine, across all 12 survey years.[15] Mean dietary fiber intake was statistically different by sex (P <.001), with males consuming higher amounts of dietary fiber. Younger adults had mean dietary fiber intakes that were not statistically different across survey years (P = .28), while older adults had mean dietary fiber intakes that tended to increase across survey years (P <.001). College graduates had higher mean dietary fiber intakes than other groups (P <.001), although trends by education were not linear. Additionally, mean dietary fiber intake was statistically different by race/ethnicity (P <.001), with Mexican Americans consuming higher amounts of dietary fiber and non-Hispanic blacks consuming lower amounts of dietary fiber compared with non-Hispanic whites. Young non-Hispanic black men aged 20-50 years had a mean fiber intake (14.7 g) that was furthest from the recommended adequate intake for their age group (38 g). Older Mexican American (15.6 g) and non-Hispanic white women (15.0 g) aged 51 years and older had fiber intake that was closest to recommended levels for their age group (21 g). Mexican Americans and non-Hispanic blacks had mean dietary fiber intake patterns that were not statistically different across survey years (P = .21 and P = .17, respectively), while non-Hispanic whites had mean dietary fiber intakes that increased marginally across survey years (P = .05).

Table 1 Descriptive Characteristics for all Nonpregnant Adults 20+ Years by Dietary Fiber, NHANES 1999-2010

	Unadjusted Mean Dietary Fiber Intake	
	Total n (%)	Dietary Fiber (g) ± SE
Demographics		
Total population, %	23,168 (100)	16.2 ± 0.2
Age		
20-50 years	11,794 (59.8)	16.1 ± 0.2
51+ years	11,374 (40.2)	16.2 ± 0.2
Sex		
Male	11,761 (49.5)	18.0 ± 0.2
Female	11,407 (50.5)	14.3 ± 0.2
Race/ethnicity		
Mexican American	5257 (8.6)	18.8 ± 0.2
Non-Hispanic white	13,009 (80.0)	16.3 ± 0.2
Non-Hispanic black	4902 (11.5)	13.1 ± 0.2
Education		
<9th grade	3099 (5.8)	16.1 ± 0.3
9th-12th grade, but no HS diploma	3804 (12.5)	14.4 ± 0.2
HS diploma/GED	5670 (25.9)	14.9 ± 0.2
Some college, Associate's degree	6194 (30.2)	15.7 ± 0.2
Bachelor's degree or greater	4401 (25.6)	18.8 ± 0.3
Behaviors		
Smoking status		
Current smoker	5232 (23.7)	13.6 ± 0.2
Former smoker	6266 (26.0)	17.0 ± 0.2
Never smoker	11,670 (50.3)	16.9 ± 0.2
Physical activity 1999-2006[a]		
No activity	6106 (34.6)	14.6 ± 0.2
Some/irregular activity	3279 (25.1)	15.8 ± 0.2
Regular activity	4989 (40.3)	17.2 ± 0.3
Physical activity 2007-2010[a]		
No activity	4812 (47.2)	14.9 ± 0.2
Some/irregular activity	1326 (17.3)	16.9 ± 0.5
Regular activity	2635 (35.5)	18.6 ± 0.4
Energy intake (kcal/day)[b]		
Low (below guidelines)	9746 (36.6)	12.1 ± 0.2
Adequate (meets guidelines)	4892 (24.8)	23.1 ± 0.5
High (above guidelines)	8530 (38.6)	16.9 ± 0.3

GED = General Educational Development test; HS = high school; NHANES = National Health and Nutrition Examination Survey.

[a]Due to methodological changes in physical activity measurement between 2006 and 2007, physical activity was assessed separately in 1999-2006 and 2007-2010. Physical activity categories based on the US Department of Health and Human Services' 2008 Physical Activity Guidelines for Americans.[32] "No activity" includes participants with no moderate or vigorous physical activity. "Some/Irregular activity" includes participants with <150 minutes/week of moderate activity or <75 minutes/week of vigorous activity. "Regular activity" includes participants with ≥150 minutes/week of moderate activity, ≥75 minutes/week of vigorous activity, or ≥150 minutes/week of a combination of moderate and vigorous activity.

[b]Energy intake categories based on the US Department of Health and Human Services' 2010 Dietary Guidelines for Americans.[27] "Low" includes males with <2000 kcal/day and females with <1600 kcal/day. "Adequate" includes males with 2000-3000 kcal/day and females with 1600-2400 kcal/day. "High" includes males with >3000 kcal/day and females with >2400 kcal/day.

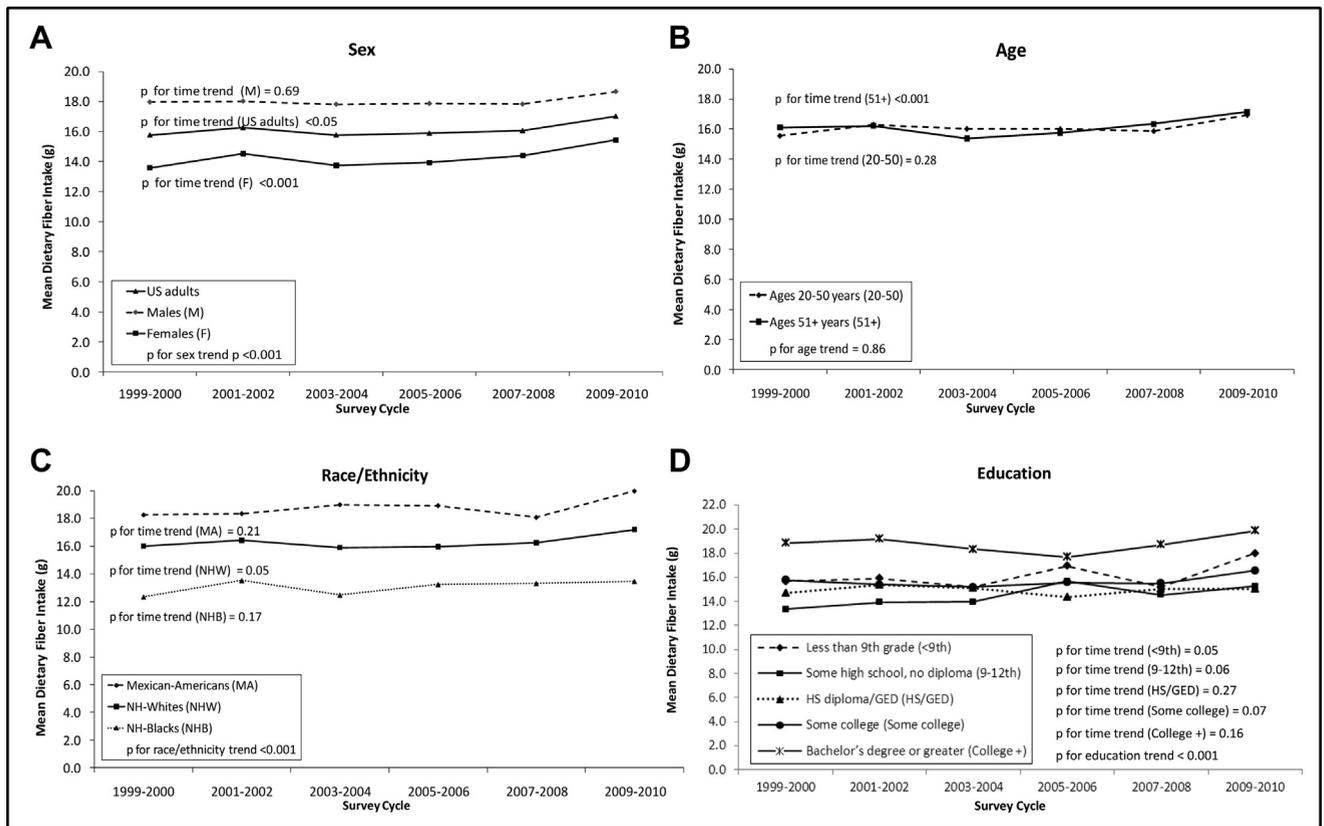Data from the National Health and Nutrition Examination Survey, 1999-2010.

Dietary Fiber and Cardiometabolic Risks

The prevalence estimates of the metabolic syndrome, elevated CRP, and obesity are displayed in Table 2 by sociodemographic and behavioral characteristics. Overall, participants with the metabolic syndrome, elevated CRP, and obesity consumed lower amounts of dietary fiber but also had lower reported energy intake.

The unadjusted prevalence of cardiometabolic risks by quintiles of dietary fiber intake is presented in Figure 2.

Overall, the prevalence of the metabolic syndrome, inflammation, and obesity each decreased with increasing quintiles of dietary fiber intake ($P <.05$, $P <.001$, and $P <.001$, respectively). The highest unadjusted prevalence of the metabolic syndrome (34.7%), inflammation (43.5%), and obesity (36.4%) was observed among participants in the lowest quintile of dietary fiber intake (0.0-8.1 g).

In Table 3, weighted multivariable regression models demonstrated an inverse association between dietary fiber

Figure 1 Trends in mean dietary fiber intake among nonpregnant US adults by sex, age, race/ethnicity, and education in NHANES 1999-2010. Data from National Health and Nutrition Examination Survey, 1999-2010.

intake and cardiometabolic risks. After adjusting for covariates, participants with higher intakes of dietary fiber were less likely to have the metabolic syndrome, inflammation, and be obese. This trend was consistent after adjusting for age, total energy intake, sex, race/ethnicity, educational attainment, and smoking status. Compared with participants in the lowest quintile of dietary fiber intake, participants in the highest quintile of dietary fiber intake had a statistically significant lower risk of having the metabolic syndrome (RR 0.78; 95% CI, 0.70-0.88), inflammation (RR 0.66; 95% CI, 0.61-0.72), and obesity (RR 0.77; 95% CI, 0.71-0.84). Adding physical activity to the multivariable models produced similar results for adults in NHANES 1999-2006 and NHANES 2007-2010 (Appendix 1, online). Additionally, excluding participants with "extreme" dietary fiber intakes did not change our findings (Appendix 2, online).

Associations stratified by racial/ethnic group differed by the cardiometabolic risk studied. Statistically significant decreases in the prevalence of inflammation were associated with increasing dietary fiber intakes for all groups. Statistically significant decreases in the risk of obesity and the metabolic syndrome were seen only among whites, although a protective trend was observed in all groups (Appendix 3, online).

DISCUSSION

Our findings indicate that, among a nationally representative sample of nonpregnant US adults in NHANES 1999-2010, the consumption of dietary fiber was consistently below the recommended total adequate intake levels across survey years. Our study also confirms persistent differences in dietary fiber intake among sex, socioeconomic status, and racial/ethnic subpopulations over time.[33] On average, young males consumed almost 20 g less dietary fiber than recommended amounts, with particularly low consumption by young non-Hispanic black men. Older women had dietary fiber intakes that were closest to, yet still an average of 6 g below, recommended amounts of fiber for their age group. Importantly, lower dietary fiber intake was associated with a higher prevalence of cardiometabolic risks among US adults.

Our findings are consistent with prior literature suggesting a lack of improvement in US dietary fiber intake trends over time, as well as sociodemographic differences in fiber intake.[16,19,33] These data support prior recommendations to improve strategies that increase dietary fiber intake among US adults.[34] To this end, the 2010 Scientific Statement from the American Heart Association on interventions to improve lifestyle changes in dietary intake and physical activity reviewed over 74 studies, and

Table 2 Descriptive Characteristics for all Nonpregnant Adults 20+ Years by Presence of Metabolic Syndrome,[a] Inflammation,[b] and Obesity,[b] NHANES 1999-2010

	Metabolic Syndrome Present[a] n = 3780	Metabolic Syndrome Absent[a] n = 6693	C-reactive Protein >3.0 mg/L n = 8877	C-reactive Protein ≤3.0 mg/L n = 14,291	Body Mass Index ≥30.0 kg/m² n = 8158	Body Mass Index <30.0 kg/m² n = 15,010
Demographics						
Total population, %	32.3	67.7	34.9	65.1	33.5	66.5
Age, %						
20-50 years	23.9	76.1	31.4	68.6	31.7	68.3
51+ years	45.0	55.0	40.1	59.9	36.1	63.9
Sex, %						
Male	32.7	67.3	27.8	72.3	31.8	68.2
Female	31.9	68.1	42.0	58.1	35.2	64.8
Race/ethnicity, %						
Mexican American	33.4	66.6	36.7	63.3	35.5	64.5
Non-Hispanic white	32.9	67.1	33.6	66.4	31.7	68.3
Non-Hispanic black	27.0	73.0	42.5	57.5	44.3	55.7
Education, %						
<9th grade	40.7	59.3	40.4	59.6	34.8	65.2
9th-12th grade, but no HS diploma	38.7	61.3	41.3	58.7	36.6	63.4
HS diploma/GED	37.9	62.1	37.0	63.1	35.3	64.7
Some college, Associate's degree	31.5	68.5	35.7	64.3	36.1	63.9
Bachelor's degree or greater	22.6	77.4	27.5	72.5	26.7	73.3
Behaviors						
Smoking status, %						
Current smoker	29.5	70.5	37.9	62.1	27.1	72.9
Former smoker	38.3	61.7	35.9	64.1	36.4	63.6
Never smoker	30.4	69.6	33.0	67.0	35.0	65.0
Dietary intake						
Mean dietary fiber intake, g (± SE)	15.5 ± 0.2	16.3 ± 0.2	14.5 ± 0.2	17.0 ± 0.2	15.5 ± 0.2	16.5 ± 0.2
Mean energy intake,[c] kcal (± SE)	2147.8 ± 21.4	2261.3 ± 15.5	2082.4 ± 14.4	2304.6 ± 11.8	2190.6 ± 16.0	2245.3 ± 11.7
Physical activity 1999-2006[d], %						
No activity	39.7	60.3	43.8	56.2	37.6	62.4
Some/irregular activity	34.6	65.4	36.2	63.8	34.4	65.6
Regular activity	25.3	74.7	29.3	70.7	26.5	73.5
Physical activity 2007-2010[d], %						
No activity	40.2	59.8	40.1	59.9	42.1	57.9
Some/irregular activity	28.3	71.7	32.2	67.9	34.3	65.7
Regular activity	22.7	77.3	23.6	76.4	27.8	72.3

GED = General Educational Development test; HS = high school; NHANES = National Health and Nutrition Examination Survey.

[a]The Adult Treatment panel (ATP)III clinical criteria were used to define metabolic syndrome. Metabolic syndrome was defined as having at least 3 of the 5 following cardiometabolic risk factors: high waist circumference (waist circumference >102 cm for males or >88 cm for females); elevated blood pressure (blood pressure ≥130/85 mm Hg); elevated triglycerides (triglyceride concentration ≥150 mg/dL); low high-density lipoprotein (HDL) cholesterol (HDL cholesterol levels <40 mg/dL for males or <50 mg/dL for females); and elevated fasting glucose (fasting plasma glucose ≥100 mg/dL).

[b]Inflammation was defined as having a C-reactive protein concentration >3.0 mg/L, while obesity was characterized as having a body mass index ≥30 kg/m².

[c]Energy intake categories based on the US Department of Health and Human Services' 2010 Dietary Guidelines for Americans.[27] "Low" includes males with <2000 kcal/day and females with <1600 kcal/day. "Adequate" includes males with 2000-3000 kcal/day and females with 1600-2400 kcal/day. "High" includes males with >3000 kcal/day and females with >2400 kcal/day.

[d]Due to methodological changes in physical activity measurement between 2006 and 2007, physical activity was assessed separately in 1999-2006 and 2007-2010. Physical activity categories based on the US Department of Health and Human Services' 2008 Physical Activity Guidelines for Americans.[32] "No activity" includes participants with no moderate or vigorous physical activity. "Some/Irregular activity" includes participants with <150 minutes/week of moderate activity or <75 minutes/week of vigorous activity. "Regular activity" includes participants with ≥150 minutes/week of moderate activity, ≥75 minutes/week of vigorous activity, or ≥150 minutes/week of a combination of moderate and vigorous activity.

Data from National Health and Nutrition Examination Survey, 1999-2010.
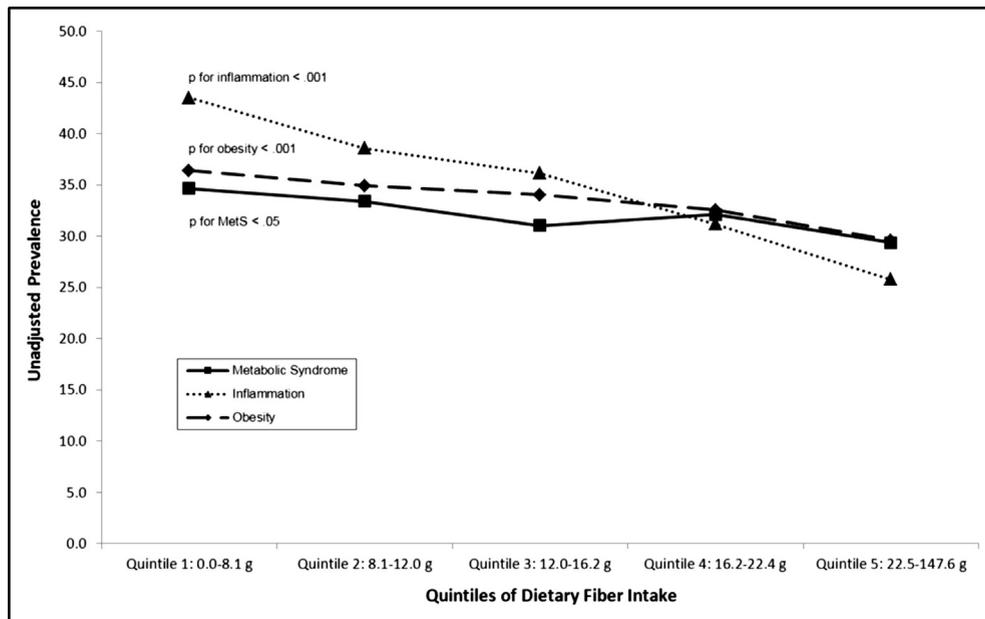
Figure 2 Prevalence of cardiometabolic risks by quintiles of dietary fiber intake among nonpregnant adults aged 20+ years, in NHANES 1999-2010. Data from National Health and Nutrition Examination Survey, 1999-2010.

describe 18 interventions directed toward increasing fruit and vegetable intake; 6 of the studies focused on increasing fiber intake.[35] Successful approaches to increase fiber intake included: individual-based counseling from health educators using goal setting, problem solving, and telephone follow-up for support and reinforcement; group and individual sessions that employ reflective listening and self-monitoring techniques; as well as community- and Internet-based strategies, including interventions at point of sale in supermarkets.[36-40] Additional research is needed to determine effective clinical and population-based strategies for improving fiber intake trends in diverse groups.

Our study has strengths and limitations that should be considered. We cannot infer causal interpretations of the relation between dietary fiber intake and cardiometabolic risks due to the cross-sectional design of the study. Moreover, we were unable to estimate separate associations between cardiometabolic risks and soluble or insoluble fiber, fiber supplements, or with specific sources of fiber that may have differential impacts on cardiovascular disease risks.[2,10,41] Recent small-scale intervention studies have used dietary sources and psyllium supplements at high levels (at or in excess of 30 g/day) to achieve reductions in inflammation, body mass index, and other cardiometabolic risk factors.[42,43] Additional large-scale epidemiologic and randomized intervention studies are needed to refine recommendations on the sources and quantities of dietary fiber, or fiber from supplemental sources, that may lower cardiometabolic risks in diverse groups.

Table 3 Predicted Marginal Risk Ratios for Cardiometabolic Risk Factors, Based on Quintiles of Dietary Fiber Intake and Other Individual Covariates—Nonpregnant Adults 20+ Years in NHANES 1999-2010

	Predicted Marginal Risk Ratios (95% CI)[a]		
Quintiles of Dietary Fiber	Metabolic Syndrome Fully Adjusted[b]	Inflammation Fully Adjusted[b]	Obese Fully Adjusted[b]
0.0-8.1 g	1.00	1.00	1.00
8.1-12.0 g	0.91 (0.82-1.00)	0.90 (0.84-0.95)	0.94 (0.88-1.00)
12.0-16.2 g	0.85 (0.76-0.93)	0.86 (0.80-0.93)	0.89 (0.83-0.95)
16.2-22.4 g	0.84 (0.75-0.93)	0.76 (0.70-0.82)	0.85 (0.80-0.92)
22.5-147.6 g	0.78 (0.70-0.88)	0.66 (0.61-0.72)	0.77 (0.71-0.84)

CI = confidence interval; NHANES = National Health and Nutrition Examination Survey.
[a]Estimates weighted to account for complex survey design in SUDAAN.
[b]Fully adjusted: models adjusted for age, total energy intake, sex, race/ethnicity, educational attainment, and smoking status.
Data from National Health and Nutrition Examination Survey, 1999-2010.

Additional limitations include the fact that we reported dietary fiber intake, and did not report on functional or synthetic (supplemental) fiber intake, which may underestimate total fiber intake of US adults. Moreover, we modeled dietary fiber intake based on a single 24-hour dietary recall survey, which may have led to misclassification of fiber intake. We also cannot exclude recall bias during the assessment of sources of fiber intake. Validation study data from Conway et al[44,45] suggest that the US Department of Agriculture 5-step multiple-pass dietary recall methodology used by NHANES provides self-reported macronutrient and energy intake that are within 10% of actual intakes among men and women.[44,45] Additionally, we note that earlier nationally representative data collected between 1995 and 1996 from the National Institutes of Health (NIH) AARP Diet and Health study provide a more complete assessment of fiber intake than the NHANES surveys by using 124-item food-frequency questionnaires to collect data on usual frequency of intake over 12 months, and with data from 2 nonconsecutive 24-hour recalls.[1] Similar to the NHANES estimates, NIH AARP data also reported similarly low fiber intake, with energy-adjusted dietary fiber values ranging from 11 and 13 g/day for women and men, respectively, at the 10th percentile of intake, to 26 to 29 g/day at the 90th percentile. Such data are consistent with our results using a single 24-hour recall to assess fiber intake.

Despite the above limitations, our study has important strengths, including the large nationally representative sample in NHANES that allows examination of trends in diverse groups. Additionally, our results are robust to the potential influence of extreme reporting of fiber intake.

In summary, our study shows that fiber consumption among US adults has remained consistently low between 1999 and 2010. There also are significant differences in dietary fiber intake by sex, racial/ethnicity, and socioeconomic status. Our findings underscore the need for additional randomized controlled trial data to shape recommendations for dietary fiber intake as a preventive strategy to reduce associated cardiometabolic risks. Additional nutritional policies may be needed to increase adequate consumption of dietary fiber, in order to reduce cardiometabolic risk factors in diverse US populations. Continued monitoring and surveillance of fiber intake trends also are warranted.

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Appendix 1a Sensitivity Analysis for Physical Activity: Predicted Marginal Risk Ratios for Metabolic Syndrome, Based on Quintiles of Dietary Fiber Intake and Other Individual Covariates—Nonpregnant Adults 20+ Years in NHANES 1999-2010

| | Predicted Marginal Risk Ratios (95% CI) for Metabolic Syndrome | | | | | |
| | NHANES 1999-2006 | | | NHANES 2007-2010 | | |
Quintiles of Dietary Fiber	Age-Adjusted[a]	Fully Adjusted 1[b]	Fully Adjusted 2[c]	Age-Adjusted[a]	Fully Adjusted 1[b]	Fully Adjusted 2[c]
0.0-8.1 g	1.00	1.00	1.00	1.00	1.00	1.00
8.1-12.0 g	0.93 (0.83-1.06)	0.93 (0.82-1.05)	0.95 (0.84-1.07)	0.84 (0.70-1.00)	0.85 (0.71-1.02)	0.87 (0.72-1.04)
12.0-16.2 g	0.92 (0.81-1.04)	0.93 (0.82-1.06)	0.95 (0.84-1.08)	0.65 (0.55-0.76)	0.67 (0.57-0.80)	0.68 (0.58-0.81)
16.2-22.4 g	0.85 (0.74-0.99)	0.86 (0.75-1.00)	0.88 (0.77-1.02)	0.75 (0.65-0.86)	0.78 (0.67-0.91)	0.81 (0.70-0.94)
22.5-147.6 g	0.79 (0.69-0.91)	0.80 (0.69-0.93)	0.83 (0.72-0.97)	0.70 (0.57-0.86)	0.74 (0.61-0.91)	0.79 (0.65-0.96)

CI = confidence interval; NHANES = National Health and Nutrition Examination Survey.
[a]Age-adjusted models only adjusted for age and total energy intake.
[b]Fully adjusted 1 models adjusted for age, total energy intake, sex, race/ethnicity, educational attainment, and smoking status.
[c]Fully adjusted 2 models adjusted for age, total energy intake, sex, race/ethnicity, educational attainment, smoking status, and physical activity.
Data from National Health and Nutrition Examination Survey, 1999-2010. Estimates weighted to account for complex survey design in SUDAAN.

Appendix 1b Sensitivity Analysis for Physical Activity: Predicted Marginal Risk Ratios for Inflammation, Based on Quintiles of Dietary Fiber Intake and Other Individual Covariates—Nonpregnant Adults 20+ Years in NHANES 1999-2010

| | Predicted Marginal Risk Ratios (95% CI) for Inflammation | | | | | |
| | NHANES 1999-2006 | | | NHANES 2007-2010 | | |
Quintiles of Dietary Fiber	Age-Adjusted[a]	Fully Adjusted 1[b]	Fully Adjusted 2[c]	Age Adjusted[a]	Fully Adjusted 1[b]	Fully Adjusted 2[c]
0.0-8.1 g	1.00	1.00	1.00	1.00	1.00	1.00
8.1-12.0 g	0.88 (0.81-0.94)	0.90 (0.84-0.98)	0.91 (0.85-0.98)	0.85 (0.76-0.95)	0.88 (0.79-0.99)	0.89 (0.80-1.00)
12.0-16.2 g	0.82 (0.75-0.89)	0.87 (0.80-0.95)	0.88 (0.81-0.96)	0.77 (0.68-0.88)	0.84 (0.74-0.96)	0.86 (0.75-0.97)
16.2-22.4 g	0.71 (0.65-0.78)	0.78 (0.71-0.86)	0.80 (0.73-0.88)	0.64 (0.55-0.74)	0.72 (0.62-0.83)	0.74 (0.65-0.85)
22.5-147.6 g	0.57 (0.51-0.62)	0.66 (0.60-0.73)	0.68 (0.62-0.75)	0.57 (0.50-0.64)	0.68 (0.60-0.77)	0.72 (0.64-0.82)

CI = confidence interval; NHANES = National Health and Nutrition Examination Survey.
[a]Age-adjusted models only adjusted for age and total energy intake.
[b]Fully adjusted 1 models adjusted for age, total energy intake, sex, race/ethnicity, educational attainment, and smoking status.
[c]Fully adjusted 2 models adjusted for age, total energy intake, sex, race/ethnicity, educational attainment, smoking status, and physical activity.
Data from National Health and Nutrition Examination Survey, 1999-2010. Estimates weighted to account for complex survey design in SUDAAN.

Appendix 1c Sensitivity Analysis for Physical Activity: Predicted Marginal Risk Ratios for Obesity, Based on Quintiles of Dietary Fiber Intake and Other Individual Covariates—Nonpregnant Adults 20+ Years in NHANES 1999-2010

	Predicted Marginal Risk Ratios (95% CI) for Obesity					
	NHANES 1999-2006			NHANES 2007-2010		
Quintiles of Dietary Fiber	Age Adjusted[a]	Fully Adjusted 1[b]	Fully Adjusted 2[c]	Age Adjusted[a]	Fully Adjusted 1[b]	Fully Adjusted 2[c]
0.0-8.1 g	1.00	1.00	1.00	1.00	1.00	1.00
8.1-12.0 g	0.92 (0.84-1.00)	0.92 (0.84-1.00)	0.93 (0.85-1.01)	0.96 (0.87-1.06)	0.96 (0.87-1.05)	0.97 (0.87-1.08)
12.0-16.2 g	0.91 (0.83-1.00)	0.93 (0.85-1.02)	0.94 (0.86-1.03)	0.82 (0.77-0.88)	0.82 (0.76-0.88)	0.83 (0.77-0.90)
16.2-22.4 g	0.84 (0.77-0.91)	0.86 (0.79-0.93)	0.88 (0.81-0.96)	0.83 (0.72-0.96)	0.84 (0.74-0.95)	0.87 (0.77-0.98)
22.5-147.6 g	0.74 (0.66-0.82)	0.77 (0.69-0.86)	0.79 (0.71-0.89)	0.76 (0.66-0.87)	0.77 (0.68-0.88)	0.82 (0.72-0.93)

CI = confidence interval; NHANES = National Health and Nutrition Examination Survey.
[a]Age-adjusted models only adjusted for age and total energy intake.
[b]Fully adjusted 1 models adjusted for age, total energy intake, sex, race/ethnicity, educational attainment, and smoking status.
[c]Fully adjusted 2 models adjusted for age, total energy intake, sex, race/ethnicity, educational attainment, smoking status, and physical activity.
Data from National Health and Nutrition Examination Survey, 1999-2010. Estimates weighted to account for complex survey design in SUDAAN.

Appendix 2a Exclusion of Dietary Fiber Intakes in the 5th and 95th Percentile[a]: Predicted Marginal Risk Ratios for Cardiometabolic Risk Factors, Based on Quintiles of Dietary Fiber Intake and Other Individual Covariates—Nonpregnant Adults 20+ Years in NHANES 1999-2010

	Predicted Marginal Risk Ratios (95% CI)					
	Metabolic Syndrome		Inflammation		Obesity	
Quintiles of Dietary Fiber	Age Adjusted[b]	Fully Adjusted[c]	Age Adjusted[b]	Fully Adjusted[c]	Age Adjusted[b]	Fully Adjusted[c]
4.2-8.1 g	1.00	1.00	1.00	1.00	1.00	1.00
8.1-12.0 g	0.92 (0.84-1.02)	0.93 (0.84-1.02)	0.90 (0.84-0.96)	0.93 (0.86-0.99)	0.95 (0.88-1.01)	0.94 (0.88-1.01)
12.0-16.2 g	0.84 (0.77-0.93)	0.86 (0.78-0.95)	0.83 (0.76-0.90)	0.89 (0.82-0.96)	0.89 (0.83-0.95)	0.89 (0.83-0.96)
16.2-22.4 g	0.83 (0.75-0.92)	0.85 (0.77-0.94)	0.71 (0.65-0.77)	0.78 (0.72-0.84)	0.84 (0.78-0.91)	0.86 (0.79-0.92)
22.5-34.4 g	0.78 (0.70-0.88)	0.81 (0.71-0.91)	0.60 (0.55-0.66)	0.70 (0.64-0.76)	0.75 (0.69-0.82)	0.77 (0.70-0.84)

CI = confidence interval; NHANES = National Health and Nutrition Examination Survey.
[a]Dietary fiber intakes <4.20 g were considered to be in the 5th percentile and dietary fiber intakes >34.40 g were considered to be in the 95th percentile of intakes, and were excluded from this analysis.
[b]Age-adjusted models adjusted for age and total energy intake.
[c]Fully adjusted models adjusted for age, total energy intake, sex, race/ethnicity, educational attainment, and smoking status.
Data from National Health and Nutrition Examination Survey, 1999-2008. Estimates weighted to account for complex survey design in SUDAAN.

Appendix 2b Exclusion of Dietary Fiber Intakes in the 1st and 99th Percentile[a]: Predicted Marginal Risk Ratios for Cardiometabolic Risk Factors, Based on Quintiles of Dietary Fiber Intake and Other Individual Covariates—Nonpregnant Adults 20+ Years in NHANES 1999-2010

	Predicted Marginal Risk Ratios (95% CI)					
	Metabolic Syndrome		Inflammation		Obesity	
Quintiles of Dietary Fiber	Age Adjusted[b]	Fully Adjusted[c]	Age Adjusted[b]	Fully Adjusted[c]	Age Adjusted[b]	Fully Adjusted[c]
1.8-8.1 g	1.00	1.00	1.00	1.00	1.00	1.00
8.1-12.0 g	0.91 (0.83-1.00)	0.91 (0.83-1.00)	0.87 (0.82-0.93)	0.90 (0.85-0.96)	0.94 (0.88-1.01)	0.94 (0.88-1.00)
12.0-16.2 g	0.83 (0.76-0.92)	0.85 (0.77-0.94)	0.81 (0.75-0.87)	0.87 (0.81-0.94)	0.89 (0.83-0.95)	0.89 (0.84-0.95)
16.2-22.4 g	0.82 (0.74-0.91)	0.84 (0.76-0.93)	0.69 (0.64-0.75)	0.76 (0.70-0.82)	0.85 (0.79-0.91)	0.86 (0.80-0.92)
22.5-50.54 g	0.77 (0.69-0.85)	0.79 (0.70-0.88)	0.57 (0.53-0.62)	0.67 (0.61-0.72)	0.76 (0.69-0.82)	0.78 (0.71-0.84)

CI = confidence interval; NHANES = National Health and Nutrition Examination Survey.

[a]Dietary fiber intakes <1.80 g were considered to be in the 1st percentile and dietary fiber intakes >50.54 g were considered to be in the top 99th percentile of intakes, and were excluded from this analysis.

[b]Age-adjusted models adjusted for age and total energy intake.

[c]Fully adjusted models adjusted for age, total energy intake, sex, race/ethnicity, educational attainment, and smoking status.

Data from National Health and Nutrition Examination Survey, 1999-2008. Estimates weighted to account for complex survey design in SUDAAN.

Appendix 3   Predicted Marginal Risk Ratios for Metabolic Syndrome, Inflammation, and Obesity,[a] Based on Quintiles of Dietary Fiber Intake and Other Individual Covariates—Nonpregnant Adults 20+ Years in NHANES 1999-2010

	Fully Adjusted Predicted Marginal Risk Ratios[b] (95% CI)		
	Mexican American	NH Black	NH White
Quintiles of dietary fiber associated with metabolic syndrome	n = 2417	n = 2124	n = 5932
0.0-8.1 g	1.00	1.00	1.00
8.1-12.0 g	0.73 (0.57-0.93)	0.86 (0.70-1.04)	0.93 (0.83-1.04)
12.0-16.2 g	0.77 (0.62-0.96)	0.80 (0.66-0.98)	0.86 (0.76-0.97)
16.2-22.4 g	0.78 (0.63-0.96)	0.89 (0.69-1.16)	0.84 (0.74-0.95)
22.5-147.6 g	0.90 (0.72-1.12)	0.91 (0.71-1.18)	0.75 (0.65-0.87)
Quintiles of dietary fiber associated with inflammation	n = 5257	n = 4902	n = 13,009
0.0-8.1 g	1.00	1.00	1.00
8.1-12.0 g	0.89 (0.78-1.02)	0.96 (0.87-1.06)	0.88 (0.82-0.95)
12.0-16.2 g	0.87 (0.77-0.99)	0.90 (0.81-1.00)	0.85 (0.78-0.93)
16.2-22.4 g	0.86 (0.77-0.97)	0.84 (0.73-0.96)	0.73 (0.67-0.81)
22.5-147.6 g	0.85 (0.76-0.95)	0.85 (0.74-0.97)	0.62 (0.57-0.68)
Quintiles of dietary fiber associated with obesity	n = 5257	n = 4902	n = 13,009
0.0-8.1 g	1.00	1.00	1.00
8.1-12.0 g	0.86 (0.74-1.00)	1.01 (0.92-1.11)	0.93 (0.86-1.00)
12.0-16.2 g	0.90 (0.78-1.05)	0.97 (0.88-1.07)	0.88 (0.81-0.95)
16.2-22.4 g	0.85 (0.74-0.98)	0.91 (0.81-1.03)	0.85 (0.77-0.92)
22.5-147.6 g	0.89 (0.76-1.03)	0.81 (0.70-0.95)	0.75 (0.67-0.84)

CI = confidence interval; NHANES = National Health and Nutrition Examination Survey.
[a]Obese defined as body mass index (BMI) ≥30 and not obese defined as BMI <30.
[b]Fully adjusted: models adjusted for age, total energy intake, sex, educational attainment, and smoking status.
Data from National Health and Nutrition Examination Survey, 1999-2010. Estimates weighted to account for complex survey design in SUDAAN.