ORIGINAL ARTICLE

Dietary Fiber Intake in Relation to Knee Pain Trajectory

ZHAOLI DAI, NA LU, JINGBO NIU, DAVID T. FELSON, AND YUQING ZHANG

Objective. Dietary fiber may reduce knee pain, in part by lowering body weight and reducing inflammation. In this study, we assessed whether fiber intake was associated with patterns of knee pain development.

Methods. In a prospective, multicenter cohort of 4,796 men and women ages 45–79 years with or at risk of knee osteoarthritis, participants underwent annual followups for 8 years. Dietary fiber intake was estimated using a validated food frequency questionnaire at baseline. Group-based trajectory modeling was used to identify Western Ontario and McMaster Universities Osteoarthritis Index pain trajectories, which were assessed for associations with dietary fiber intake using polytomous regression models.

Results. Of the eligible participants (4,470 persons and 8,940 knees, mean ± SD age 61.3 ± 9.1 years, 58% women), 4.9% underwent knee replacement and were censored at the time of surgery. Four distinct knee pain patterns were identified: no pain (34.5%), mild pain (38.1%), moderate pain (21.2%), and severe pain (6.2%). Dietary total fiber was inversely related to membership in the moderate or severe pain groups ($P \leq 0.006$ for trend for both). Subjects in the highest versus those in the lowest quartile of total fiber intake had a lower risk of belonging to the moderate pain pattern group (odds ratio [OR] 0.76 [95% confidence interval (95% CI) 0.61–0.93]) and severe pain pattern group (OR 0.56 [95% CI 0.41–0.78]). Similar results were found with grain fiber and these 2 pain pattern groups.

Conclusion. Our findings suggest that a high intake of dietary total or grain fiber, particularly the recommended daily fiber average intake of 25 gm per day, is associated with a lower risk of developing moderate or severe knee pain over time.

INTRODUCTION

Osteoarthritis (OA) is the most common form of arthritis and is characterized by synovial inflammation, destruction of cartilage, and joint pain (1). Chronic pain and loss of function are the primary causes of disability in OA patients. Although nonsteroidal antiinflammatory drugs (NSAIDs) are currently the most widely used medication to relieve pain symptoms of OA, they are known to cause side effects, including gastrointestinal symptoms and internal bleeding, particularly in the elderly (2,3). Dietary approaches to therapy may provide safe alternative options for pain management in those with or at risk of painful knee OA.

Dietary fibers are carbohydrates that are indigestible or nonabsorbable by the small intestine but partially or fully fermentable in the colon (4). The health-related physiological properties of dietary fiber include reduced energy density (5) and lowered adiposity and inflammation through desirable microbes in the gut (6), both of which facilitate weight loss (7–10) and decrease proinflammatory markers (11–14). Epidemiologic studies have consistently reported that dietary total fiber and particularly fiber from whole-grain cereals are associated with lower risks of mortality (15,16), cardiovascular disease (CVD) (17), type 2

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Significance & Innovations

- Dietary approaches for knee pain management are lacking.
- This study is the first to show an association between higher dietary fiber intake and a lower risk of moderate or severe knee pain.
- Such protective associations were found to persist regardless of radiographic knee osteoarthritis status.

diabetes mellitus (18–21), and depression (22,23), in part because dietary fiber lowers body weight and reduces inflammation. In these studies, fiber from cereal grains, rather than that from fruits, vegetables, legumes, and nuts, was a prominent protective factor (15–17,20,21,24,25).

OA shares common risk factors with other metabolic diseases, including CVD and diabetes mellitus (26), in which obesity and inflammation are strongly associated with pain symptoms related to OA. To our knowledge, there are no data to date on the relationship of dietary fiber intake with knee pain in older adults. In this study, we examined the associations between dietary fiber intake and knee pain development patterns over a period of 8 years.

MATERIALS AND METHODS

Study population. We used data from the Osteoarthritis Initiative (OAI), a multicenter, longitudinal prospective cohort of 4,796 US men (41.5% of total) and women ages 45–79 years with or at high risk of knee OA recruited from 2004 to 2006. The criteria for participation in the OAI were the absence of rheumatoid arthritis or other forms of inflammatory arthritis at the study screening. Details of the study protocol have been published previously (27). After enrollment, participants were followed annually for up to 96 months. In this study, we further excluded those who had total or partial knee replacement (KR) at baseline (n = 63). Institutional review board approval was obtained from all study sites, and all study participants gave informed consent.

Exposure measure: baseline assessment of dietary fiber. At the baseline assessment, participants' usual eating habits were recorded using the Block Brief 2000 food frequency questionnaire (FFQ). The Block Brief 2000 FFQ contains 60 food items, is a reduced questionnaire developed from the validated Block Full FFQ (28,29), and has been further validated against multiple dietary records in different studies (29). The 2 Block FFQs showed similar correlation coefficients for major nutrients (28,29). For each food item, participants were asked, on average, how often they consumed the food in the past year according to 9 predetermined categories with illustrated portion sizes. For example, for "dark bread like rye or whole wheat,

including in sandwiches," portion sizes ranged from 1/4 cup to 2 cups. Estimation of total fiber (sum of subcategory fibers) and fiber from major food groups (cereal grain, fruits and vegetables, and nuts and legumes) was calculated based on the food composition database for nutrients in the Second National Health and Nutrition Examination Survey (28). Eligible participants were then divided into quartiles of fiber intake, separated by sex to account for sex differences in food intake.

Other covariates. During the enrollment clinic visit, a self-administered questionnaire with standard instructions was used to collect information on demographics, tobacco and alcohol use, and depressive symptoms estimated by the Center for Epidemiologic Studies Depression Scale (CES-D). A clinic visit interview was done to record history of knee injury and surgery (including KR), medication use, and physical activity as assessed by the Physical Activity Scale for the Elderly (PASE). At baseline and at each annual examination, each participant obtained a fixed-flexion posterioroanterior radiograph evaluation for both knees, scored using the Kellgren/Lawrence (K/L) grading system (range 0–4). Radiographic OA was defined as a K/L grade ≥2.

Outcome measure: knee symptom assessment of pain. At each examination at baseline and annually up to 96 months, knee symptom assessment was conducted using the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) pain subscale of 5 activity items (walking, stair climbing, nocturnal, rest, and weight bearing, scored 0–4, where 0 = no difficulty and 4 = extreme difficulty). The total possible WOMAC pain score ranged 0–20 points, where 0 = no pain and 20 = worst pain.

Statistical analysis. We further excluded participants who had missing dietary information (n = 14) or extreme daily calorie intake at baseline (<500 kcal or ≥4,200 kcal for men and ≥4,000 kcal for women, n = 249) from the analyses. In addition, participants who had KR, died, or for whom contact was lost at the time of the event during the 96-month followup were censored in the trajectory-modeling analysis. Because improvement in WOMAC pain score was noted between baseline and month 12 for all pain patterns, we evaluated the WOMAC pain trajectory pattern starting at month 12, and conducted additional analysis that started from the baseline visit.

Group-based trajectories. A group-based trajectory modeling procedure (SAS Proc Traj) (30) was applied to identify distinct WOMAC trajectories of pain over the 8-year study course. In this procedure, a multinomial modeling strategy was used to identify relatively homogenous clusters of developmental trajectories within a sample population, where the trajectory parameters are derived by latent class analysis using maximum likelihood estimation. The number of trajectories was determined by the patterns of change in WOMAC pain score and was not forced to fit a particular model regarding the number or shape of patterns. Of the eligible participants, the majority (95%) had at least 3 WOMAC scores. For

Table 1. Baseline characteristics of study participants by quartile (Q) intake of dietary total fiber*

	Q1 (lowest) (n = 2,239)	Q2 (n = 2,231)	Q3 (n = 2,236)	Q4 (highest) (n = 2,234)
Age at baseline, mean ± SD years	59.7 ± 9.0	60.9 ± 9.1	61.8 ± 9.1	62.7 ± 9.1
White	1,753 (78.3)	1,863 (83.5)	1,827 (81.7)	1,794 (80.3)
Women	1,301 (58.1)	1,296 (58.1)	1,286 (57.5)	1,296 (58.0)
Body mass index, mean ± SD kg/m^2				
At baseline	29.4 ± 5.0	28.8 ± 4.7	28.6 ± 4.7	27.6 ± 4.4
At 96-month examination	29.7 ± 5.6	28.8 ± 5.1	28.5 ± 4.8	27.8 ± 4.7
Tobacco use				
Never	1,782 (79.6)	1,763 (79.0)	1,726 (77.2)	1,785 (79.9)
Former	368 (16.5)	384 (17.2)	434 (19.4)	389 (17.4)
Current	89 (4.0)	84 (3.8)	76 (3.4)	60 (2.7)
Education				
Less than college	1,041 (46.5)	895 (40.1)	827 (37.0)	753 (33.7)
College or above	1,798 (53.5)	1,336 (59.9)	1,409 (63.0)	1,481 (66.3)
PASE score, mean ± SD	156.1 ± 80.9	160.0 ± 81.7	163.2 ± 79.9	166.4 ± 84.1
Use of NSAIDs	616 (27.5)	580 (26.0)	523 (23.4)	500 (22.4)
K/L grade				
0–1	1,187 (53.0)	1,248 (55.9)	1,263 (56.4)	1,300 (58.2)
2–4	1,052 (47.0)	983 (44.1)	973 (43.6)	934 (41.8)
WOMAC (range 0–20), mean ± SD				
At baseline	2.75 ± 3.58	2.29 ± 3.02	2.26 ± 3.14	2.08 ± 3.02
At 12-month examination	2.55 ± 3.65	2.06 ± 3.04	2.09 ± 3.06	1.78 ± 2.76
Depression				
CES-D <16	1,917 (85.6)	2,021 (90.6)	2,046 (91.5)	2,069 (92.6)
CES-D ≥16	322 (14.4)	210 (9.4)	190 (8.5)	165 (7.4)
Total kcal/day, median (IQR)	1,333.5 (974.9–1,728.5)	1,354.1 (1,044.2–1,734.0)	1,314.0 (1,008.3–1,691.9)	1,287.3 (978.3–1,640.1)
Total dietary fiber, gm/day, median (IQR)	8.6 (6.3–11.3)	12.5 (9.9–15.6)	15.2 (12.2–19.0)	20.6 (16.2–26.5)
Grain fiber, gm/day, median (IQR)	3.7 (2.5–5.2)	5.0 (3.5–6.8)	5.7 (3.9–8.0)	6.8 (4.5–9.8)
Fruit and vegetable fiber, gm/day, median (IQR)	3.8 (2.6–5.4)	6.1 (4.5–8.1)	7.8 (6.0–10.0)	10.5 (7.8–14.0)
Nut and legume fiber, gm/day, median (IQR)	0.8 (0.4–1.4)	1.4 (0.8–2.1)	1.6 (1.0–2.6)	2.3 (1.2–4.0)

* Values are the number (%) unless otherwise indicated. All differences between quartiles of total fiber intake were statistically significant at $P < 0.01$, except for sex distribution ($P = 0.98$) and tobacco use ($P = 0.056$). PASE = Physical Activity Scale for the Elderly; NSAIDs = nonsteroidal antiinflammatory drugs; K/L = Kellgren/Lawrence; WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index; CES-D = Center for Epidemiologic Depression Scale; IQR = interquartile range.

each trajectory, we chose to estimate several possible combinations of WOMAC trajectory shapes (linear, quadratic, or cubic) to identify the model by maximizing the Bayesian information criterion while maintaining the statistical significance of the model terms. The optimal number of WOMAC pain development patterns was assessed using model fit, with the average posterior probabilities of group membership at least 0.7 (31), which implies the greatest likelihood of each person's assignment in one of the patterns generated.

We used the residual method (32) to estimate dietary fiber intake separately for men and women. The association of a higher relative to the lowest quartile of fiber with pain trajectories was examined using a multivariable polytomous regression model for nominal outcomes (pain patterns) after controlling for baseline risk factors and potential confounders including age (years), sex (men versus women), race (white versus nonwhite), education (below college versus college or above), tobacco use (never, former, and current smokers), physical activity (PASE, continuous), total energy intake (kcal), prescribed or self-reported use of NSAIDs (yes/no), depressive symptoms (CES-D), and baseline radiographic OA status (K/L grade ≥2 versus K/L grade <2). Adjustment for total energy intake in addition to energy-adjusted fiber intake was based on the multivariate residual model developed by Willet for nutrients and disease outcomes in epidemiologic studies (32) and includes adjustment for total energy intake, because total energy intake not only affects dietary fiber consumption but is associated with disease outcomes due to its influence on body size, physical activity level, and metabolic efficiency (32). For other covariates selected in the full model, we took into account previously published risk factors for OA, and made adjustments for age, sex, genetic/racial differences, tobacco use, physical activity, and NSAID use (1,33,34). Linear trends were tested using the sex-specific median value of each quartile of dietary fiber as a continuous variable in the regression model. Because dietary fiber was previously suggested to lower body weight (7–10) and depression (22,23), both of which have been shown to be linked to symptomatic OA (1,34–38), body mass index (BMI; kg/m^2) and depression (CES-D score <16 versus ≥16 as a cutoff for clinical depression) (39) were not adjusted for in the primary analysis. However, in secondary analyses, we adjusted for both covariates. No evidence suggested significant

differences between men and women regarding pain trajectories or the association with dietary fiber, so we combined men and women in the analyses. In the secondary analyses, we assessed pain trajectories in participants with and without prevalent radiographic OA at baseline (KL grade ≥2) to assess whether dietary fiber had a consistent impact on pain patterns.

In addition, we carried out a sensitivity analysis including 1 knee with maximum WOMAC or a random knee per individual if the 2 knees had the same WOMAC pain score, because Proc Traj does not account for the correlation between 2 knees in an individual. All statistical analysis was conducted using SAS, version 9.3. A 2-sided *P* value less than 0.05 was considered statistically significant.

RESULTS

Baseline characteristics across quartiles of dietary total fiber intake among all eligible participants are shown in Table 1. Those who consumed more dietary fiber tended to be older and more educated, have lower BMI, and less likely to smoke. They were also more physically active, less likely to use NSAIDs, had a lower prevalence of depression, and had a lower total calorie intake, compared to participants who consumed less dietary fiber. A lower WOMAC pain score was observed as fiber intake increased at baseline and at the 12-month examination.

Of the originally enrolled 4,796 participants, excluding those who had KR at baseline (n = 63), missing dietary information (n = 14), or extreme caloric intake (n = 249), by the 96-month examination, 540 (11%) were lost to followup, including 252 deaths (5.3%). Four distinct pain trajectory patterns were identified in the 4,470 eligible participants (8,940 knees) regardless of radiographic OA status at baseline from month 12 to month 96 (Figure 1) after adjustment for the aforementioned covariates. These patterns include no pain (34.5%), mild pain (38.1%), moderate pain (21.2%), and severe pain (6.2%). The average posterior probability for each WOMAC pain trajectory group ranged from 0.87 to 0.91, indicating high discrimination in group assignment. In general, none of the trajectories suggested substantial worsening or improvement of
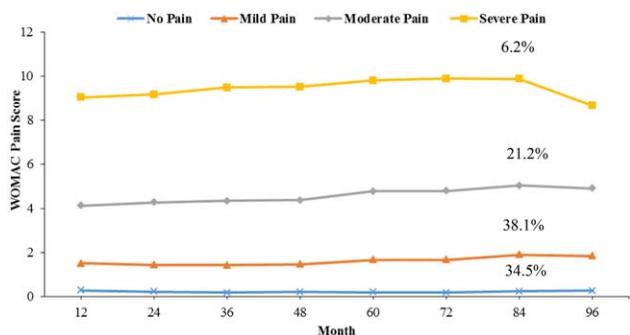
pain over time among the 4 pain patterns. The no pain trajectory group showed a consistent pain score throughout the 8-year course, with a mean WOMAC score of 0.28 (95% confidence interval [95% CI] 0.15–0.24) for month 12 and 0.26 (95% CI 0.15–0.24) for month 96. A similar shape was found in the mild pain pattern group (1.50 [95% CI 1.37–1.54] for month 12 and 1.84 [95% CI 1.75–2.03] for month 96) and in the moderate pain pattern group (4.13 [95% CI 3.87–4.39] for month 12 and 4.91 [95% CI 4.77–5.26] for month 96). In the severe pain pattern group, the average WOMAC score was 9.02 (95% CI 8.51–9.20) for month 12 and 8.65 (95% CI 8.63–9.41) for month 96. In the severe pain pattern group, there was a modest increase in WOMAC pain score until month 84, followed by a decline at month 96, which is most likely due to the censoring of KR cases after month 72. The trajectory groups of knee pain starting at baseline were very close to those beginning with month 12, comprising 4 patterns (no pain [33.9%], mild pain [37.8%], moderate pain [21.7%], and severe pain [6.6%]), with the average posterior probability ranging from 0.88 to 0.92.

Those who consumed the most total fiber (quartile 4) had the highest proportion in the no pain group (38.1%) and the lowest proportion in the severe pain group (4.3%) (Table 2). Using the no pain group as the reference, we observed that a high intake of total fiber was associated with lower risk of moderate or severe pain (*P* < 0.01 for trend for both). Compared to those in the lowest-quartile fiber intake group, participants in the highest quartile had a 24% lower likelihood of belonging to the moderate pain pattern group (odds ratio [OR] 0.76 [95% CI 0.61–0.93]) and a 44% lower risk of being in the severe pain pattern group (OR 0.56 [95% CI 0.41–0.98]). No association was found between dietary total fiber intake and mild pain. Similar results were observed for cereal grain fiber intake and pain patterns, with a significant inverse relationship with the severe pain group and a marginally significant relationship with the moderate pain group. No apparent relationship was found between pain and fiber from fruits and vegetables or legumes and nuts.

When we restricted analysis to the participants with radiographic OA at baseline (3,703 knees), 4 distinct pain patterns were identified, similar to the findings in all eligible participants, as shown in Figure 1, although there was a smaller proportion in the no pain group (26.1%) and a higher proportion in the severe pain group (7.9%) (Figure 2). The average posterior probability for each pattern ranged from 0.85 to 0.90. Again, we found 4 similar pain patterns if we started with baseline WOMAC pain scores, with 26.8% in the no pain group, 40.5% in the mild pain group, 25.3% in the moderate pain group, and 7.4% in the severe pain group.

The relationship between dietary fiber and pain in participants with prevalent radiographic OA (Table 3) was comparable to the distributions of WOMAC pain patterns in each quartile of dietary fibers but with a greater effect magnitude for the association between dietary total fiber and moderate or severe pain patterns. A significant inverse relationship was also found between grain fiber and severe pain patterns (*P* < 0.01 for trend). For fiber from fruits and vegetables, we found an inverse

Figure 1. Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) knee pain trajectory groups (n = 4,470) over 8 years of followup among all eligible participants starting from month 12.

Table 2. Dietary fiber intake and WOMAC pain subgroups among eligible participants regardless of radiographic OA status at baseline*

	Dietary fiber, gm/day, no. (%)				Adjusted odds ratio (95% confidence interval)†			
	Q1 (lowest) (n = 2,239)	Q2 (n = 2,231)	Q3 (n = 2,236)	Q4 (highest) (n = 2,234)	Q2 vs. Q1	Q3 vs. Q1	Q4 vs. Q1	P for trend
Total fiber								
No pain	719 (32.1)	754 (33.8)	807 (36.2)	851 (38.1)	1.0	1.0	1.0	
Mild pain	846 (37.8)	937 (42.0)	863 (38.6)	907 (40.6)	1.16 (0.97–1.39)	0.92 (0.77–1.10)	1.05 (0.88–1.26)	0.92
Moderate pain	488 (21.8)	433 (19.4)	434 (19.4)	380 (17.0)	0.92 (0.75–1.13)	0.85 (0.70–1.04)	0.76 (0.61–0.93)	0.006
Severe pain	186 (8.3)	107 (4.8)	132 (5.9)	96 (4.3)	0.65 (0.48–0.89)	0.79 (0.59–1.07)	0.56 (0.41–0.78)	0.002
Cereal grain fiber								
No pain	734 (32.8)	745 (33.4)	785 (35.1)	867 (38.8)	1.0	1.0	1.0	
Mild pain	840 (37.5)	910 (40.8)	912 (40.8)	889 (39.8)	1.10 (0.92–1.31)	1.00 (0.84–1.20)	0.99 (0.83–1.18)	0.49
Moderate pain	481 (21.5)	428 (19.2)	436 (19.5)	391 (17.5)	0.89 (0.73–1.10)	0.93 (0.76–1.13)	0.85 (0.70–1.04)	0.09
Severe pain	184 (8.2)	147 (6.6)	103 (4.6)	87 (3.9)	0.95 (0.71–1.28)	0.70 (0.51–0.97)	0.55 (0.39–0.79)	0.0002
Fruit and vegetable fiber								
No pain	750 (33.5)	779 (34.9)	783 (35.0)	818 (36.6)	1.0	1.0	1.0	
Mild pain	873 (39.0)	906 (40.6)	901 (40.3)	876 (39.2)	1.10 (0.92–1.31)	1.14 (0.95–1.36)	1.01 (0.84–1.21)	0.96
Moderate pain	463 (20.7)	431 (19.3)	432 (19.3)	411 (18.4)	0.91 (0.75–1.12)	0.98 (0.80–1.20)	0.80 (0.66–0.99)	0.05
Severe pain	152 (6.8)	116 (5.2)	121 (5.4)	130 (5.8)	0.92 (0.67–1.27)	1.02 (0.74–1.40)	0.84 (0.61–1.15)	0.30
Legumes and nuts fiber								
No pain	752 (33.6)	796 (35.7)	785 (35.1)	800 (35.8)	1.0	1.0	1.0	
Mild pain	862 (38.5)	890 (39.9)	879 (39.3)	923 (41.3)	0.98 (0.82–1.17)	1.02 (0.85–1.22)	1.09 (0.92–1.30)	0.21
Moderate pain	448 (20.0)	440 (19.7)	443 (19.9)	404 (18.1)	0.92 (0.75–1.12)	0.99 (0.81–1.22)	0.87 (0.70–1.07)	0.26
Severe pain	177 (7.9)	105 (4.7)	130 (5.8)	107 (4.8)	0.63 (0.46–0.87)	0.86 (0.63–1.16)	0.75 (0.55–1.03)	0.29

* Numbers given for each quartile (Q) are for numbers of knees. WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index; OA = osteoarthritis.
† Model adjusted for age (years), sex (men vs. women), race (white vs. nonwhite), education level (below vs. college or above), tobacco use (never, former, or current smokers), total calorie intake (kcal), physical activity (Physical Activity Scale for the Elderly score, continuous), baseline radiographic OA status (yes vs. no), and nonsteroidal antiinflammatory drug use (yes vs. no).
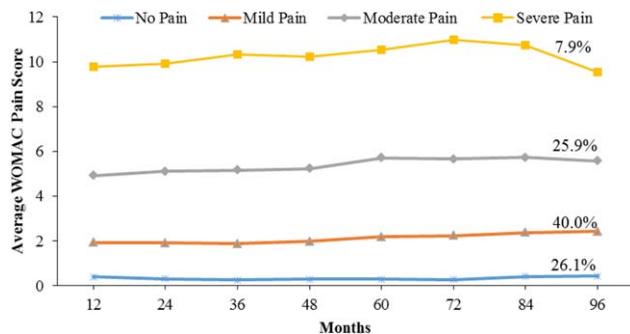
Figure 2. Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) knee pain trajectory groups (n = 1,852) over 8 years of followup among participants with radiographic OA at baseline starting from month 12. Color figure can be viewed in the online issue, which is available at http://onlinelibrary.wiley.com/doi/10.1002/acr.23158/abstract.

relationship for moderate and severe pain groups ($P \leq 0.02$ for trend for both). No significant associations were found between pain and fiber from nuts and legumes.

We found similar results in the sensitivity analyses we conducted, which included further adjustment for baseline BMI and depression (CES-D); starting from WOMAC pain score at baseline; using only 1 knee per subject with maximum or equal WOMAC pain score; and restricting analysis to those without radiographic OA at baseline. Although the results were attenuated with further adjustment for BMI and CES-D, the effect estimates remained statistically significant for the highest quartile of total or cereal grain fiber intake and severe pain pattern in all sensitivity analyses. For example, further adjustment for BMI and CES-D for both knees among all participants, regardless of baseline radiographic OA, the OR was 0.71 (95% CI 0.50–0.99) for the highest quartile of total fiber intake and 0.63 (0.44–0.90) for the highest quartile of grain fiber intake. If we followed WOMAC pain score from baseline, the associations were materially the same, with an OR of 0.70 (95% CI 0.50–0.96) for the highest quartile of total fiber intake and 0.62 (95% CI 0.44–0.88) for the highest quartile of cereal grain fiber intake ($P < 0.01$ for trend). Among those without radiographic OA at baseline, a similar protective association was found with total fiber intake in the moderate pain group ($P = 0.01$ for trend) and severe pain group ($P = 0.06$ for trend). Again, no significant results were found for fiber from fruits and vegetables or nuts and legumes.

DISCUSSION

In the present study, we identified 4 distinct WOMAC knee pain trajectory patterns over an 8-year course and found that dietary total or cereal grain fiber intake was inversely associated with the likelihood of having moderate or severe pain. In the highest quartile of total fiber intake, significantly lower odds of moderate and severe pain patterns were found, as compared with the lowest quartile, using "no pain" as the reference group. Such

associations were more apparent among persons with prevalent radiographic OA.

Our findings were consistent with those of Collins et al (40), who identified 5 WOMAC knee pain trajectories among the participants who had radiographic OA and WOMAC pain score >0 at baseline and were followed for 6 years. We included eligible participants regardless of their radiographic OA status at baseline and with WOMAC pain score ≥0 up to 8 years. Compared to the patterns Collins et al identified (40), we had a slightly higher posterior probability, ranging from 0.87 to 0.92 (versus 0.80 to 0.87). The proportion of subjects in the severe pain group is similar in the 2 studies, and the slight divergence between our patterns and theirs could be due to the rescaling of WOMAC score to >0 to 100, in addition to other criteria (status of radiographic OA and WOMAC score). Nonetheless, the pain trajectories in our study and in the Collins et al study (40) are consistent, showing that WOMAC pain score did not change substantially over time and was primarily determined by the baseline score.

To our knowledge, this is the first study to examine dietary fiber and WOMAC pain trajectory patterns that found a protective association regarding moderate and severe pain patterns. Participants in these 2 subgroups, in general, were heavier, less physically active, and less educated; they also had more risk factors for OA, such as depression and structural deterioration in the joint, which we adjusted for in analyses. We also noted that subjects whose knee pain worsened, with worsening defined as a change in WOMAC pain score of more than 14% between baseline and each annual examination (41), were primarily categorized as having moderate and severe pain patterns. In knee OA, obesity contributes to increased loading in weight-bearing joints (1,35), as well as inflammation (36), both of which have been linked to joint pain (37,38,42,43). And previous epidemiologic studies consistently showed that a high intake of dietary total fiber, particularly cereal grain fiber, was associated with lower risks of CVD and type 2 diabetes mellitus (20,21) via reduced body weight (7,8,44,45) and inflammation (11–14). Therefore, it is biologically plausible that older persons who consumed more fiber could experience less persistent moderate and severe knee pain related to OA. Possible reasons that cereal grain fiber may be more healthful than fiber from other plant sources are that whole grain wheat and bran cereals are the major source of dietary and cereal fiber (27,28); and as cereal fiber is consumed in the form of a whole food, a natural package of nutrients such as antioxidant vitamins, minerals, and unique phytochemicals found in whole grain may exert a greater antioxidant and antiinflammatory effect compared to fruits and vegetables (24,25,46), when grain is the major energy source.

When the analysis was restricted to participants with prevalent radiographic OA at baseline, we observed a stronger inverse relationship between dietary total fiber intake and severe pain. This is in line with our hypothesis that dietary fiber may reduce the risk of painful knee OA, presuming that those with prevalent radiographic OA could further develop pain symptoms. The results were consistent when we included only participants without radiographic OA at baseline. Using 1 knee with maximum

Table 3. Dietary fiber intake and WOMAC pain subgroups among eligible participants with radiographic OA at baseline*

	Dietary fiber, gm/day, no. (%)				Adjusted odds ratio (95% confidence interval)†			
	Q1 (lowest) (n = 976)	Q2 (n = 929)	Q3 (n = 920)	Q4 (highest) (n = 878)	Q2 vs. Q1	Q3 vs. Q1	Q4 vs. Q1	P for trend
Total fiber								
No pain	221 (22.6)	248 (26.7)	264 (28.7)	268 (30.5)	1.00	1.00	1.00	
Mild pain	378 (38.7)	374 (40.3)	346 (37.6)	369 (42.0)	0.88 (0.66–1.17)	0.76 (0.58–1.01)	0.87 (0.65–1.16)	0.28
Moderate pain	269 (27.6)	240 (25.8)	240 (26.1)	189 (21.5)	0.76 (0.57–1.02)	0.70 (0.52–0.94)	0.57 (0.42–0.77)	0.0004
Severe pain	108 (11.1)	67 (7.2)	70 (7.6)	53 (6.0)	0.59 (0.38–0.90)	0.61 (0.39–0.93)	0.41 (0.24–0.68)	0.0006
Cereal grain fiber								
No pain	252 (25.8)	223 (24.0)	259 (28.1)	268 (30.5)	1.00	1.00	1.00	
Mild pain	366 (37.5)	388 (41.8)	376 (40.9)	335 (38.2)	1.28 (0.96–1.69)	1.00 (0.76–1.31)	1.01 (0.77–1.33)	0.6
Moderate pain	257 (26.3)	234 (25.2)	221 (24.0)	227 (25.8)	1.08 (0.80–1.45)	0.91 (0.68–1.22)	0.98 (0.73–1.32)	0.59
Severe pain	102 (10.4)	84 (9.0)	64 (7.0)	48 (5.5)	1.04 (0.69–1.57)	0.65 (0.41–1.03)	0.55 (0.33–0.91)	0.006
Fruit and vegetable fiber								
No pain	247 (25.3)	244 (26.3)	239 (26.0)	267 (30.4)	1.00	1.00	1.00	
Mild pain	367 (37.6)	369 (39.7)	384 (41.7)	345 (39.3)	1.13 (0.84–1.51)	1.17 (0.88–1.56)	0.90 (0.68–1.20)	0.35
Moderate pain	268 (27.5)	243 (26.2)	230 (25.0)	199 (22.7)	0.93 (0.69–1.25)	0.85 (0.63–1.15)	0.60 (0.45–0.81)	0.0004
Severe pain	94 (9.6)	72 (7.8)	67 (7.3)	67 (7.6)	0.89 (0.57–1.39)	0.85 (0.55–1.33)	0.61 (0.39–0.95)	0.02
Legumes and nuts fiber								
No pain	247 (25.3)	242 (26.0)	269 (29.2)	243 (27.7)	1.00	1.00	1.00	
Mild pain	380 (38.9)	382 (41.1)	334 (36.3)	371 (42.2)	1.03 (0.78–1.36)	0.88 (0.67–1.17)	1.09 (0.83–1.44)	0.57
Moderate pain	245 (25.1)	242 (26.1)	245 (26.6)	208 (23.7)	0.98 (0.73–1.32)	0.92 (0.69–1.23)	0.77 (0.57–1.05)	0.09
Severe pain	104 (10.7)	63 (6.8)	73 (7.9)	56 (6.4)	0.60 (0.38–0.94)	0.70 (0.46–1.09)	0.69 (0.44–1.09)	0.23

* Numbers given for each quartile (Q) are for numbers of knees. WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index; OA = osteoarthritis.
† Model adjusted for age (years), sex (men vs. women), race (white vs. nonwhite), education level (below vs. college or above), tobacco use (never, former, or current smokers), total calorie intake (kcal), physical activity (Physical Activity Scale for the Elderly score, continuous), and nonsteroidal antiinflammatory drug use (yes vs. no).

or equal WOMAC score also yielded materially the same results as using 2 knees per subject. Although we found consistent patterns and associations using WOMAC from baseline or month 12, we conducted our primary analysis starting at month 12 in order to minimize bias in the observed improvement of WOMAC scores in all patterns from baseline to month 12. Overall, these sensitivity analyses demonstrated consistent results and yielded high discrimination for the 4 distinct patterns generated in this study. Furthermore, consistent associations were found between dietary total fiber and grain fiber and moderate and severe pain patterns.

Although we included all possible established risk factors and confounders for WOMAC knee pain trajectory and also controlled for BMI and CES-D in our secondary analysis, we could not rule out the possibility of residual confounding by factors such as diet quality (47). Additionally, while dietary fiber from fruits, vegetables, and legumes would be related to healthier diet and lifestyle, only total and cereal grain fibers were shown to be associated with a lower risk of moderate or severe knee pain. Hence, residual confounding by other healthful food components or lifestyle factors that may account for the relationship we observed in the present study seems unlikely.

Strengths of this study include the prospective cohort design and the relatively large sample size. The 4 distinct WOMAC pain patterns showed more than 0.87 in average posterior probability for each pain group, indicating very high discrimination and good model fit. During the 8-year followup to assess the prospective relationship between dietary fiber at baseline and pain patterns over time, we carefully carried out censoring techniques to account for those who experienced knee replacement, were lost to followup, or died at the time of the event to ensure a complete inclusion of all eligible participants in the trajectory analysis.

Limitations in terms of dietary information included no followup data on dietary information, which precluded us from assessing changes in dietary fiber intake, although dietary fiber intake has been reported to be rather stable. For example, the average fiber intake in US adults was 15.6 gm/day in 1999–2000 and increased to 15.9 gm/day in 2007–2008 in the National Health and Nutrition Examination Survey (48), a slight increment that could also have been present in our sample. The subtle change, if present, should not alter the effects estimates substantially and would have likely attenuated the observed associations. Another limitation is that each WOMAC pain development pattern is relatively steady over time, where participants' pain scores were primarily determined by their baseline levels. Although this is consistent with the findings of the previous study of pain trajectory (40) and with other trajectory studies, such as those on depression (49) and gait speed (50), this scenario could be due to the so-called horseracing effect, in which a prolonged condition that has been ongoing before the baseline observation would in general maintain its baseline level over time, unless the important risk factors under investigation, such as dietary intake for WOMAC pain, also change substantially during the study period. But, as mentioned, dietary fiber intake changes little over time; thus, such a stable exposure limits our ability to examine the association between modified dietary fiber intake and WOMAC knee pain patterns over time. A well-designed intervention study would be helpful for answering such a question. Finally, results from observational studies often cannot generate causality, as there may have been residual/unmeasured confounding factors. In conclusion, our findings suggest that greater dietary intake of total and cereal grain fiber, particularly in the recommended daily fiber average intake of 25 grams per day, is related to lower likelihood of having moderate to severe pain over 8 years.

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