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Dietary Fiber, Magnesium, and Glycemic Load Alter Risk of Type 2 Diabetes in a Multiethnic Cohort in Hawaii[1,2]

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Abstract

The influence of dietary fiber, magnesium (Mg), and glycemic load (GL) on diabetes was examined in the Hawaii component of the Multiethnic Cohort. The 75,512 Caucasian, Japanese American, and Native Hawaiian participants aged 45–75 y at baseline completed a FFQ. After 14 y of follow-up, 8587 incident diabetes cases were identified through self-reports and health plans. We applied Cox regression stratified for age at cohort entry and adjusted for ethnicity, BMI, physical activity, education, and total energy with further stratifications by sex and ethnicity. When comparing extreme quintiles, total fiber intake was associated with reduced diabetes risk among all men [hazard ratio (HR): 0.75; 95% CI: 0.67, 0.84; P-trend < 0.001) and women (HR: 0.95; 95% CI: 0.85, 1.06; P-trend $= 0.05$). High intake of grain fiber reduced diabetes risk significantly by 10% in men and women. High vegetable fiber intake lowered risk by 22% in all men but not women. Mg intake reduced risk (HR = 0.77 and 0.84 for men and women, respectively) and, due to its strong correlation with fiber ($r = 0.83$; $P < 0.001$), may explain the protective effect of fiber. The top GL quintile was associated with a significantly elevated diabetes incidence in Caucasian men and in all women except Japanese Americans. Overall, several associations were more pronounced in Caucasians than in the other groups. These findings suggest that protection against diabetes can be achieved through food choices after taking into account body weight, but, due to differences in commonly consumed foods, risk estimates may differ by ethnic group. J. Nutr. 140: 68–74, 2010.

Introduction

In the Multiethnic Cohort (MEC),[5] very high diabetes incidence rates (per 1000 person-years) were observed for Native Hawaiians (17.5 in men and 15.9 in women) and Japanese Americans (16.2 in men and 12.7 in women) compared with Caucasians (7.1 in men and 4.9 in women) (1). Because these ethnic differences in risk could only be partially explained by BMI, we took further advantage of the prospective study design to examine the effect of specific nutrients on diabetes risk (1–3).

Fiber, especially soluble fiber found in fruits and legumes, improves satiety by providing bulk and increasing digestion time (4,5). The mechanism for this action is thought to be the ability of dietary fiber to slow postprandial glucose uptake, thereby producing lower blood glucose and insulin levels (6). Fiber intake has been linked to lower body weight, which may be responsible for the lower diabetes risk observed in several investigations (6). Insoluble fiber, commonly found in grains and vegetables, may improve hepatic insulin sensitivity through the production of SCFA in the colon (7). Also, components of fiber-containing foods (8), in particular magnesium (Mg), are thought to act through hormonal regulation of glucose homeostasis (9). Mg, which is abundant in nuts, legumes, grains, dairy, and some fruits and vegetables, was inversely associated with diabetes risk in a recent meta-analysis, with a risk estimate of 0.77 (95% CI: 0.72–0.84) when extreme categories were compared (7).

Glycemic load (GL) has been hypothesized as a predictor of diabetes due to its effect on blood glucose response (10–12). Digestion rates and blood glucose response vary considerably depending on the type of carbohydrate in a food (4). The glycemic index is a relative measure of the glycemic response or insulin demand induced by carbohydrate intake. GL uses the glycemic index and the carbohydrate content of a food to estimate the effect of a specific portion of food on postprandial blood sugar levels. The chronically high insulin demand related to a diet with a high GL may lead to pancreatic β cell exhaustion, insulin resistance, glucose intolerance, and an increase in late postprandial FFA (12).

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[5] Abbreviations used: GL, glycemic load; HR, hazard ratio; MEC, Multiethnic Cohort; QFFQ, quantitative FFQ.

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Prospective studies examining the relationship between fiber, GL, and incident diabetes across multiple ethnicities are currently limited (13,14). The goal of this study was to examine the associations of dietary fiber (total fiber, grain fiber, fruit fiber, and vegetable fiber including legume fiber), Mg, and GL with diabetes in men and women of Caucasian, Japanese American, and Native Hawaiian ancestry in the MEC.

Methods

Study population. The MEC study of diet and cancer was established in 1993 through 1996 and consists of men and women aged 45–75 y from 5 major ethnic groups (Caucasian, Japanese American, Native Hawaiian, African American, and Latino) (15). Although approximately one-half of the $>$200,000 participants were recruited in California, the current analysis is limited to the Hawaii component due to the availability of diabetes incidence data (1). The Hawaii study population consists of 103,898 participants primarily from 3 ethnic groups (Caucasian, Japanese American, and Native Hawaiian) residing on 6 Hawaiian Islands. Respondents completed a 26-page, self-administered, mailed survey at baseline that included a quantitative FFQ (QFFQ) and questions about demographic information, medical conditions, anthropometric measures, and lifestyle factors (16). Japanese Americans had higher (46% for men and 51% for women) and Native Hawaiians had lower (28% for men and 35% for women) response rates than Caucasians. Nevertheless, participants in the MEC were fairly representative of the general population, as evidenced by a comparison of the cohort distributions across educational levels and marital status with corresponding census data (15). After exclusion of 10,028 self-reported prevalent cases, 8797 participants of other ethnicity, 6202 individuals with missing covariates, 2537 persons with missing dietary information, 812 self-reported cases not confirmed by a health plan, and 10 persons with missing information on follow-up, 36,256 men and 39,256 women were part of this analysis. The study protocols were approved by the Committee on Human Studies at the University of Hawaii and by the Institutional Review Board of Kaiser Permanente.

Case ascertainment. As described previously, incident diabetes cases were identified through 3 sources (1). A follow-up questionnaire was sent to MEC members between 1999 and 2003 to update information on medical conditions, including diabetes (84% of respondents of the baseline questionnaire). Between 2001 and 2007, blood and urine specimens were collected on a subset of the MEC participants who also completed a medication questionnaire at the time of blood draw that covered diabetes drugs (38% of respondents of the baseline questionnaire). Finally, the MEC data were linked with the 2 major health plans in Hawaii, Kaiser Permanente, and Blue Cross/Blue Shield in July 2007 (1). After excluding 812 self-reported cases not confirmed by a health plan, 2251 of the 8587 incident cases were identified in the follow-up questionnaire, 996 by diabetes drugs in the medication questionnaire, and 5340 cases through one of the health plans. Annual linkages with state death certificate files provided information on vital status.

QFFQ. Dietary information was collected using a QFFQ that has been described in detail elsewhere (12). In brief, the QFFQ included 8 frequency categories for foods and 9 for beverages. Portion sizes were selected from 3 or 4 options. To define the specific performance of the QFFQ on the different ethnic groups, a calibration study using 24-h recalls was performed and showed acceptable values (16). Nutrient intake was determined using a customized ethnicity-specific food composition database based on the USDA nutrient database and additional laboratory analyses performed in Hawaii (15). Daily intakes of dietary fiber and Mg from foods were converted to energy density values (per 4184 kJ). After assigning glycemic index values to each food using published values or imputations from similar foods (17), GL was calculated by multiplying the total carbohydrate content minus fiber content per serving by the glycemic index and dividing by 100.

Statistical methods. Statistical analyses were performed using SAS statistical software, version 9.1 (SAS Institute). Cox proportional hazards regression models (PROC PHREG) were applied to analyze the effect of fiber (total dietary fiber, fiber from grains, fiber from fruits, and fiber from vegetables), Mg, and GL on diabetes risk. Hazard ratio (HR) and 95% CI were calculated using follow-up time as the underlying time metric. To ensure that the estimation procedure was based on comparisons of participants at the same age, we controlled for age at cohort entry through stratification. Dietary fiber, Mg, and GL were analyzed as quintiles of the distribution among men and women separately. BMI (kg/m^2) was divided into 4 categories: $<$23.0 (reference group), 23.0–24.9 (normal weight), 25.0–29.9 (overweight), and $\geq$30.0 (obese). Due to previously reported associations with diabetes risk, ethnicity (Japanese American and Native Hawaiian vs. Caucasian), BMI as categories, physical activity (quintiles), education (13–15 and $>$15 vs. $\leq$12 y), and energy intake (log transformed) were included as covariates. Because the interaction term between sex and GL was suggestive of a differential effect ($P = 0.09$) and interactions between ethnicity and several nutrients were significant, e.g. dietary fiber in men ($P = 0.05$) and GL in women ($P = 0.03$), we further stratified the analysis by sex and ethnic group. Ordinal variables representing the medians of each quintile were included to test for linear trends. Kaplan-Meier survival curves and Schoenfeld residuals did not reveal any major violations of the proportional hazards assumption (18). For all tests, $P < 0.05$ was considered significant.

Results

After 14 y of follow-up, 8587 incident diabetes cases were identified (**Table 1**). Caucasians tended to have more education ($P < 0.0001$), followed by Japanese Americans. Native Hawaiians were more likely to have a higher BMI, whereas Japanese Americans tended to have a lower BMI ($P < 0.0001$ between all groups). The mean intake of all types of fiber was higher among all women than all men ($P < 0.0001$); Caucasians consumed the most, followed by Japanese Americans and Native Hawaiians ($P < 0.0001$). Levels of Mg intake mirrored fiber intake. Caucasian women had the lowest daily GL, whereas Native Hawaiian men had the highest.

Total dietary fiber intake was inversely associated with diabetes risk (HR: 0.75; 95% CI: 0.67, 0.84; P-trend < 0.0001) among all men (**Table 2**). After stratification, the trend test was only significant for Caucasians, but we observed significant protective effects for the top compared with the bottom quintile of intake in all groups, 25% for all men (34% for Caucasians, 16% for Japanese Americans, and 30% for Native Hawaiians), indicating a threshold effect that was also confirmed by a quadratic term ($P = 0.03$). In all women (**Table 3**), the association for dietary fiber was weaker (HR: 0.95; 95% CI: 0.85, 1.06; P-trend = 0.05), but the quadratic term was also significant ($P = 0.04$). Within ethnic groups, only Caucasian women showed an inverse trend (P-trend = 0.04). After excluding BMI from the total fiber model to test for BMI as a mediator, the HR for the top category was 0.68 for all men and 0.78 for all women, corresponding to 7 and 17% further reduction in risk, respectively, compared with the model adjusted for BMI.

In all men, grain fiber was inversely associated with diabetes risk (HR: 0.91; 95% CI: 0.82–1.00; P-trend = 0.006) and was associated with an almost 20% reduction in diabetes risk for the top categories in Caucasians and Native Hawaiians but had no apparent effect in Japanese Americans. In all women, fiber from grains was also associated with a lower risk overall when the top quintile was compared with the lowest (HR = 0.88; 95% CI: 0.79–0.97; P-trend = 0.02). The protective effect of grain fiber for all men and women was mainly driven by the significant finding among Caucasians (P-trend = 0.02 and 0.03) and to a

TABLE 1 Baseline characteristics of incident diabetes cases and noncases, the MEC Study, 1993 – 2007[1]

	Caucasian, *n* = 29,759		Japanese American, *n* = 35,244		Native Hawaiian *n* = 10,509		
Characteristics	Men, *n* = 15,116	Women, *n* = 14,643	Men, *n* = 16,572	Women, *n* = 18,672	Men, *n* = 4568	Women, *n* = 5941	All
Diabetes status, *%*							
Cases	7.1	4.9	16.2	12.7	17.5	15.9	11.4
Noncases	92.9	95.1	83.9	87.3	82.5	84.1	88.6
Age, *y*							
45–54	44.8	47.1	32.8	32.4	50.5	53.2	40.6
55–64	27.8	26.7	28.0	30.5	29.2	28.3	28.4
65+	27.5	26.2	39.2	37.1	20.3	18.6	31.0
Education, *y*							
≤12	19.0	23.2	39.1	41.2	47.6	52.4	34.1
13–15	29.0	34.3	28.8	28.1	31.9	30.1	30.0
>15	52.0	42.5	32.1	30.7	20.6	17.5	35.9
BMI, *kg/m*^{2}							
<25.0	47.2	62.5	57.6	73.9	26.7	38.6	57.1
25.0–29.9	40.6	25.1	36.7	21.4	44.2	33.4	31.6
≥30	12.3	12.5	5.7	4.6	29.1	28.0	11.2
Physical activity, *MET*[2]	1.6 (1.4, 1.8)	1.6 (1.4, 1.8)	1.6 (1.5, 1.8)	1.6 (1.4, 1.7)	1.7 (1.5, 1.9)	1.6 (1.4, 1.8)	1.6 (1.4, 1.8)
Dietary intake							
Total energy, *kJ*	9045 (7000, 11680)	7144 (5576, 9189)	9052 (7077, 11488)	7150 (5604, 9140)	10628 (7774, 14379)	8625 (6292, 11865)	8167 (6230, 10739)
Dietary fiber, *g/(4184 kJ · d)*	10.3 (8.0, 13.1)	12.0 (9.5, 15.2)	8.7 (6.7, 11.4)	11.3 (8.8, 14.2)	8.1 (6.3, 10.6)	10.1 (7.8, 13.2)	10.4 (7.9, 13.4)
Grain fiber, *g/(4184 kJ · d)*	3.1 (2.2, 4.5)	3.4 (2.4, 4.9)	2.7 (1.9, 4.0)	3.2 (2.3, 4.5)	2.4 (1.8, 3.6)	2.8 (2.1, 4.0)	3.0 (2.1, 4.4)
Fruit fiber, *g/(4184 kJ · d)*	1.8 (0.9, 3.1)	2.6 (1.4, 4.2)	1.7 (0.8, 3.1)	2.9 (1.5, 4.6)	1.4 (0.7, 2.6)	2.1 (1.1, 3.7)	2.2 (1.1, 3.7)
Vegetable fiber, *g/(4184 kJ · d)*	3.2 (2.3, 4.4)	3.9 (2.8, 5.3)	2.8 (2.1, 3.8)	3.6 (2.6, 4.8)	2.7 (2.0, 3.7)	3.4 (2.4, 4.7)	3.3 (2.4, 4.5)
Magnesium, *mg/(4184 kJ · d)*	158 (137, 184)	174 (150, 200)	149 (130, 174)	165 (143, 192)	140 (123, 162)	153 (132, 179)	159 (137, 186)
Daily GL	150 (112, 198)	125 (94, 165)	173 (132, 225)	144 (111, 186)	193 (136, 265)	163 (116, 230)	151 (112, 202)

[1] Data are percentages or median (interquartile range).

[2] Metabolic equivalents of tasks.

lesser extent by the nonsignificant risk reduction among Native Hawaiians (*P*-trend = 0.15 and 0.11).

Whereas fiber from fruit was not associated with diabetes risk in either all men or all women, fiber from vegetables had an inverse association in all men (HR: 0.78; 95% CI: 0.69, 0.88; *P*-trend < 0.0001). Caucasian and Japanese American men in the top quintiles showed risk reductions of 35 and 21%, respectively, whereas there was no association for Native Hawaiians. Vegetable fiber had no association with diabetes in women (*P*-trend = 0.38).

When comparing extreme quintiles, Mg intake was inversely associated in all men (HR: 0.77; 95% CI: 0.70; 0.85; *P*-trend < 0.0001) and all women (HR: 0.84; 95% CI: 0.76; 0.93; *P*-trend = 0.0003) in a model without adjustment for fiber (Tables 2 and 3). The association was consistent across ethnic groups in men and showed similar reductions in women, except for Japanese Americans. Possibly because the correlation between dietary fiber and Mg was high ($r = 0.83$; $P < 0.001$), the protective effect of fiber was not present in all men (HR = 0.89; 95% CI: 0.76–1.05; *P*-trend = 0.74) and all women (HR = 1.13; 95% CI: 0.96–1.32; *P*-trend = 0.23) when Mg was included into the total fiber model, whereas dietary Mg remained significant.

The association between GL and diabetes was borderline in all men (*P*-trend = 0.07) and significant in all women (HR: 1.41; 95% CI: 1.15–1.73; *P*-trend = 0.02). For Caucasians, the risk was significantly elevated by 50% in the 5th quintile among men (*P*-trend = 0.003) and doubled in women (*P*-trend = 0.002). After adjustment for total carbohydrate intake, the relation was significant among all men (*P*-trend = 0.001) and lost significance among all women (*P*-trend = 0.11). When models were mutually adjusted for dietary fiber, Mg, and GL, Mg and GL remained significant in both men and women (*P*-trend = 0.006 and 0.002 for Mg and 0.03 and 0.009 for GL), whereas dietary fiber did not (*P*-trend = 0.44 and 0.41).

Discussion

In this multiethnic population, participants in the top quintile of dietary fiber intake experienced a reduced diabetes risk, suggesting a threshold effect for daily intakes of >30 g (based on a diet of 8368 kJ). The effect was stronger in men than in women and more pronounced in Caucasians than in Japanese Americans and Native Hawaiians. As the small difference in risk between the models with and without BMI indicates, the effect was only partially mediated by body weight. Grain fiber was beneficial for men and women, vegetable fiber was protective for men only, and fiber from fruit did not affect diabetes risk in men or women. High Mg intake was associated with a lower diabetes risk in men and women and may explain the protective effect of dietary fiber. GL increased diabetes risk among Caucasian men and all women, although not all associations were significant.

This investigation was limited in several ways. Unfortunately, Mg intake from supplements could not be included in the analysis, because the FFQ did not ask for this mineral. Due to Mg's strong correlation with dietary fiber, it was difficult to disentangle their separate effects. Future investigations need to assess the degree to which dietary and supplemental Mg alters diabetes risk in relation to dietary fiber. Furthermore, the concept of GL does not consider insulin response, which might be of greater interest for diabetes prevention, because different

TABLE 2 Diabetes risk (HR) associated with dietary fiber intake and GL by ethnic group in men in the Hawaii component of the MEC Study, 1993–2007[1]

Dietary variable and category	Men, *n* = 4555		Caucasian, *n* = 1080		Japanese American, *n* = 2677		Native Hawaiian, *n* = 798	
	n[2]	HR (95%CI)	*n*	HR (95%CI)	*n*	HR (95%CI)	*n*	HR (95%CI)
Total dietary fiber, *g/(4184 kJ · d)*								
<7.4	1532	1.00	253	1.00	938	1.00	341	1.00
7.4–9.3	1113	0.98 (0.91–1.06)	269	1.02 (0.86–1.22)	657	0.96 (0.87–1.06)	187	0.96 (0.80–1.15)
9.4–11.3	7l92	0.92 (0.84–1.01)	228	0.93 (0.77–1.11)	442	0.92 (0.82–1.03)	122	0.94 (0.76–1.16)
11.4–14.1	702	0.99 (0.91–1.09)	203	0.89 (0.73–1.07)	399	1.04 (0.92–1.18)	100	1.13 (0.90–1.42)
≥14.2	416	0.75 (0.67–0.84)	127	0.66 (0.53–0.82)	241	0.84 (0.72–0.97)	48	0.70 (0.52–0.96)
P-value		<0.0001		<0.0001		0.09		0.19
Dietary fiber from grains, *g/(4184 kJ · d)*								
<1.9	1170	1.00	234	1.00	682	1.00	254	1.00
1.9–2.6	1102	1.06 (0.97–1.15)	228	1.02 (0.85–1.23)	671	1.08 (0.97–1.20)	203	1.00 (0.83–1.20)
2.7–3.4	873	0.99 (0.90–1.08)	217	0.91 (0.75–1.09)	501	0.99 (0.88–1.12)	155	1.05 (0.86–1.28)
3.5–4.7	728	0.94 (0.85–1.03)	209	0.91 (0.76–1.10)	415	0.95 (0.84–1.07)	104	0.95 (0.75–1.20)
≥ 4.8	682	0.91 (0.82–1.00)	192	0.81 (0.67–0.99)	408	0.98 (0.87–1.11)	82	0.83 (0.64–1.07)
P-value		0.006		0.02		0.30		0.15
Dietary fiber from fruits, *g/(4184 kJ · d)*								
<0.8	1259	1.00	283	1.00	717	1.00	259	1.00
0.8–1.6	1018	0.96 (0.88–1.05)	240	0.85 (0.72–1.01)	569	0.99 (0.88–1.10)	209	1.04 (0.87–1.25)
1.7–2.4	856	0.96 (0.88–1.05)	222	0.89 (0.75–1.07)	504	1.01 (0.90–1.14)	130	0.91 (0.73–1.12)
2.5–3.8	790	0.96 (0.87–1.05)	189	0.86 (0.71–1.04)	487	1.01 (0.89–1.14)	114	0.98 (0.78–1.24)
≥3.9	632	0.93 (0.84–1.02)	146	0.88 (0.71–1.08)	400	0.97 (0.85–1.11)	86	0.93 (0.72–1.19)
P-value		0.17		0.34		0.75		0.46
Dietary fiber from vegetables, *g/(4184 kJ · d)*								
<2.2	1224	1.00	263	1.00	729	1.00	232	1.00
2.2–3.0	1222	1.07 (0.98–1.15)	255	0.91 (0.77–1.09)	747	1.08 (0.97–1.19)	220	1.20 (1.00–1.45)
3.1–3.8	1006	1.04 (0.95–1.13)	256	0.96 (0.81–1.14)	591	1.03 (0.92–1.15)	159	1.12 (0.91–1.37)
3.9–5.2	764	1.00 (0.91–1.09)	200	0.84 (0.70–1.01)	440	1.01 (0.90–1.14)	124	1.16 (0.93–1.45)
≥5.3	339	0.78 (0.69–0.88)	106	0.65 (0.52–0.82)	170	0.79 (0.67–0.93)	63	0.99 (0.75–1.32)
P-value		<0.0001		0.0002		0.01		0.89
Dietary Mg intake, *mg/(4184 kJ · d)*								
<129.3	1300	1.00	253	1.00	733	1.00	314	1.00
129.4–145.8	980	0.88 (0.81–0.96)	206	0.81 (0.68–0.98)	597	0.92 (0.83–1.03)	177	0.85 (0.71–1.02)
145.9–162.1	876	0.87 (0.80–0.95)	220	0.87 (0.72–1.04)	520	0.87 (0.77–0.97)	136	0.91 (0.74–1.11)
162.2–185.3	725	0.84 (0.76–0.92)	221	0.84 (0.70–1.01)	409	0.84 (0.74–0.95)	95	0.87 (0.69–1.10)
≥185.4	674	0.77 (0.70–0.85)	180	0.65 (0.53–0.79)	418	0.85 (0.75–0.96)	76	0.79 (0.61–1.03)
P-value		<0.0001		<0.0001		0.004		0.08
GL								
Quintile 1	745	1.00	257	1.00	369	1.00	119	1.00
Quintile 2	873	1.04 (0.94–1.16)	236	1.08 (0.89–1.31)	527	1.06 (0.92–1.23)	110	0.89 (0.67–1.17)
Quintile 3	898	1.07 (0.95–1.20)	202	1.09 (0.87–1.36)	574	1.08 (0.92–1.26)	122	0.98 (0.73–1.32)
Quintile 4	1008	1.11 (0.98–1.26)	207	1.31 (1.01–1.68)	647	1.09 (0.91–1.29)	154	0.93 (0.68–1.27)
Quintile 5	1031	1.16 (0.99–1.36)	178	1.54 (1.12–2.10)	560	1.05 (0.85–1.31)	293	1.10 (0.76–1.61)
P-value		0.07		0.003		0.91		0.29

[1] Adjusted for ethnicity (Japanese American, Native Hawaiian vs. Caucasian), BMI (23.0–24.9, 25.0–29.9, and ≥30 vs. <23), physical activity (quintiles of MET), education (13–16 y and >16 y vs. ≤12 y), and calories (logarithm of continuous).

[2] *n* represents diabetes cases.

carbohydrate-containing foods with similar GL can have different effects on insulin response (19,20). Also, the high intra- and intersubject variations in insulin response to a food make it difficult to generalize findings for GL (21). Under- and overreporting of foods is common and may have occurred in this cohort (22). The relatively small sample size for Native Hawaiians limited the power to detect associations. Due to multiple comparisons, some results in this analysis might be due to chance. On the other hand, this study also had several important strengths, foremost its prospective nature with 14 y of follow-up. The Hawaii component of the MEC is a large multiethnic study population with great variations in diabetes risk. Several sources contributed to diabetes incidence data, but only cases confirmed by a health plan were included in the analysis. The prospective study design reduced the chances of recall bias for dietary exposures. Because information on the occurrence of diabetes was obtained and classified independent of dietary exposure, the possibility of information bias was greatly reduced.

The findings of this analysis agree with previous reports showing a protective effect of dietary fiber (23,24) and vegetable fiber (25–27) against diabetes. Similar associations reported for

TABLE 3 Diabetes risk (HR) associated with dietary fiber intake and GL by ethnic group in women in the Hawaii component of the MEC Study, 1993–2007[1]

Dietary variable and category	Women, *n* = 4,032		Caucasian, *n* = 715		Japanese American, *n* = 2,374		Native Hawaiian, *n* = 943	
	n[2]	HR (95%CI)	*n*	HR (95%CI)	*n*	HR (95%CI)	*n*	HR (95%CI)
Total dietary fiber, *g/(4184 kJ · d)*								
<8.9	1223	1.00	179	1.00	661	1.00	383	1.00
8.9–11.1	948	0.99 (0.91–1.08)	170	0.94 (0.76–1.17)	573	1.03 (0.92–1.16)	205	0.90 (0.76–1.08)
11.2–13.2	734	0.90 (0.82–0.98)	146	0.88 (0.70–1.09)	440	0.90 (0.80–1.02)	148	0.91 (0.75–1.11)
13.3–16.1	615	0.87 (0.79–0.97)	115	0.82 (0.65–1.04)	373	0.88 (0.77–1.00)	127	0.93 (0.75–1.15)
≥16.2	512	0.95 (0.85–1.06)	105	0.80 (0.62–1.02)	327	1.04 (0.90–1.20)	80	0.85 (0.66–1.10)
P-value		0.05		0.04		0.59		0.21
Dietary fiber from grains, *g/(4184 kJ · d)*								
<2.1	927	1.00	140	1.00	510	1.00	277	1.00
2.1–2.8	943	0.94 (0.86–1.03)	152	1.04 (0.82–1.31)	547	0.90 (0.80–1.02)	244	0.97 (0.82–1.16)
2.9–3.7	799	0.90 (0.82–0.99)	151	0.94 (0.74–1.18)	462	0.87 (0.77–0.99)	186	0.93 (0.77–1.13)
3.8–5.0	735	0.91 (0.82–1.00)	150	0.95 (0.75–1.20)	458	0.91 (0.80–1.04)	127	0.84 (0.68–1.04)
≥5.1	628	0.88 (0.79–0.97)	122	0.79 (0.62–1.01)	397	0.91 (0.79–1.04)	109	0.87 (0.69–1.09)
P-value		0.02		0.03		0.35		0.11
Dietary fiber from fruits, *g/(4184 kJ · d)*								
<2.1	1056	1.00	190	1.00	536	1.00	330	1.00
2.1–2.8	823	0.91 (0.83–0.99)	155	0.83 (0.67–1.03)	459	0.99 (0.87–1.12)	209	0.81 (0.68–0.97)
2.9–3.7	811	0.97 (0.88–1.06)	167	1.04 (0.83–1.29)	492	1.01 (0.89–1.15)	152	0.83 (0.68–1.02)
3.8–5.0	702	0.84 (0.76–0.92)	115	0.88 (0.69–1.11)	449	0.86 (0.75–0.98)	138	0.80 (0.65–0.99)
≥5.1	640	0.95 (0.85–1.06)	88	0.85 (0.65–1.11)	438	0.98 (0.85–1.12)	114	0.99 (0.79–1.24)
P-value		0.21		0.36		0.37		0.70
Dietary fiber from vegetables, *g/(4184 kJ · d)*								
<1.3	1005	1.00	154	1.00	572	1.00	279	1.00
1.3–2.3	993	1.07 (0.98–1.17)	168	1.11 (0.89–1.39)	597	1.04 (0.93–1.17)	228	1.07 (0.89–1.27)
2.4–3.4	873	1.04 (0.95–1.14)	167	1.05 (0.84–1.31)	523	1.00 (0.89–1.13)	183	1.08 (0.90–1.31)
3.5–5.1	703	1.02 (0.92–1.12)	126	0.90 (0.71–1.14)	423	1.03 (0.91–1.17)	154	1.08 (0.88–1.32)
≥5.2	458	0.96 (0.87–1.08)	100	0.94 (0.73–1.22)	259	1.00 (0.86–1.16)	99	0.92 (0.73–1.16)
P-value		0.38		0.25		0.94		0.62
Dietary Mg intake, *mg/(4184 kJ · d)*								
<139.3	1124	1.00	176	1.00	577	1.00	371	1.00
139.4–157.9	843	0.88 (0.80–0.96)	140	0.79 (0.63–0.98)	520	0.91 (0.81–1.03)	183	0.85 (0.71–1.01)
158.0–176.1	765	0.87 (0.79–0.96)	145	0.80 (0.64–1.00)	452	0.86 (0.76–0.98)	168	0.94 (0.78–1.14)
176.2–200.1	662	0.82 (0.74–0.90)	132	0.70 (0.56–0.89)	404	0.83 (0.73–0.95)	126	0.91 (0.74–1.13)
≥200.2	638	0.84 (0.76–0.93)	122	0.61 (0.48–0.78)	421	0.92 (0.81–1.05)	95	0.84 (0.66–1.06)
P-value		0.0003		<0.0001		0.12		0.18
GL								
Quintile 1	535	1.00	141	1.00	284	1.00	110	1.00
Quintile 2	744	1.19 (1.05–1.34)	158	1.34 (1.04–1.73)	475	1.17 (0.99–1.38)	111	0.97 (0.73–1.28)
Quintile 3	839	1.29 (1.13–1.48)	152	1.48 (1.10–1.99)	542	1.24 (1.02–1.50)	145	1.13 (0.84–1.51)
Quintile 4	904	1.33 (1.14–1.56)	131	1.47 (1.03–2.08)	569	1.23 (0.98–1.54)	204	1.32 (0.97–1.81)
Quintile 5	1010	1.41 (1.15–1.73)	133	2.13 (1.37–3.31)	504	1.18 (0.88–1.58)	373	1.44 (0.98–2.12)
P-value		0.02		0.002		0.98		0.03

[1] Adjusted for ethnicity (Japanese American, Native Hawaiian vs. Caucasian), BMI (23.0–24.9, 25.0–29.9, and ≥30 vs. <23), physical activity (quintiles of MET), education (13–16 y and >16 y vs. ≤12 y), and calories (logarithm of continuous).

[2] *n* represents diabetes cases.

whole-grain foods may be due to their high fiber content (28,29). In contrast to our findings, 2 previous studies found fruit fiber was inversely associated with diabetes (25,26). The combined evidence from prospective cohort studies on dietary fiber suggests that fiber from grains might have stronger risk-reducing potential than other fibers (13,23,24,30–32). However, the association of dietary fiber with diabetes was not as strong in our study as in some other reports based on cohorts (24,31,32). A possible explanation may lie in the relatively low fiber intake in the MEC; Caucasian women consumed more fiber than other ethnic groups, but their mean daily intake of 12.6 g/4184 kJ was still below the guidelines of at least 14 g/4184 kJ (4); only participants in the top quintile consumed the recommended amount. Although one study of fiber and diabetes reported higher intakes of fiber and a stronger association with diabetes (32), another one found a stronger risk with lower fiber intake (31).

The beneficial effect of dietary fiber might be due to its high Mg content, which may be protective against diabetes due to its role as an essential cofactor for enzymes involved in glucose metabolism and its effect on insulin action and glucose homeostasis (9,33–35). Our finding of an inverse association between Mg and incident diabetes risk is in agreement with a meta-analysis (9), although some cohorts found no association (7,14). Because of the very high correlation between fiber and Mg intakes, it is not possible to distinguish separate effects of these 2 components on diabetes risk as shown in another study (36). However, the fact that Mg intake was similar across all ethnicities in our study suggests that fiber may be more likely to explain the ethnic differences in diabetes incidence.

As published in previous analyses from the MEC, dietary patterns vary across ethnicity and may be responsible for the differential effects by ethnicity (37). Compared with Caucasians, Native Hawaiians were more likely and Japanese Americans were less likely to have high scores on the "fat and meat" pattern. Both groups had higher mean scores on the "vegetables" pattern and lower mean scores on the "fruit and milk" pattern than Caucasians. The protection of grain fiber against type 2 diabetes was limited to Caucasians; this may be due the different types of grains consumed across ethnic groups (38). Rice intake was ~3-fold higher in Japanese Americans and Native Hawaiians than in Caucasians (15). Wheat was more commonly consumed by Caucasians and may contain components not present in rice that play a role in diabetes prevention. Japanese American men in our study benefited more from vegetable fiber than any other type, possibly due to their higher legume consumption compared with Caucasians and Native Hawaiians (15). Legumes and vegetables provide high amounts of both soluble and insoluble fiber. Japanese men may have benefited from the combined effects of both types of fiber, although the soluble fiber in fruit did not provide a similar effect. This finding agrees with a report from Shanghai that described a protective effect of vegetable but not fruit intake against diabetes (36). Studies on fiber intake and diabetes risk in other ethnic groups are limited, but in the Atherosclerosis Risk in Communities Study, cereal fiber was protective for Caucasian but not African American participants, although the authors suggest that this difference was possibly due to the small sample size (13). The differences in associations between men and women are not easily explained. Besides being a result of different eating patterns, errors in reporting may contribute; women tend to misreport foods to align more closely with perceived social expectations (22).

In this study, GL had a greater adverse effect in women than in men. However, the Nurses' Health Study II (24) found no significant association. Another large cohort described a weak association with GL among Caucasians but not African Americans (13). We have no obvious explanation for the fact that GL was most clearly associated with risk in Caucasians and did not increase risk in Japanese Americans and in Native Hawaiian men. The high BMI among Native Hawaiians may outweigh the potential effects of any dietary component. The lack of a good anthropometric or nutritional explanation for the weaker HR related to fiber and Mg among Japanese Americans raises the possibility of a different etiology in this group. Visceral adiposity as well as a reduced ability to regulate insulin may be responsible for the disproportionately high incidence (1,39,40).

This investigation among MEC participants strengthens support for a relation of dietary fiber and GL with diabetes risk and extends the evidence to 2 non-White ethnic groups at high risk for diabetes. Whereas Japanese American men appeared to benefit most from vegetable fiber, Native Hawaiians seemed to experience more protection from grain fiber. Differences in the amount and kind of fiber-containing foods consumed by different ethnic groups may explain the discrepancies in the strength of the associations (37), but additional research is needed to determine the effects of diet on diabetes risk across ethnic groups. The high prevalence of obesity among Native Hawaiians and visceral adiposity and insulin dysfunction among Japanese Americans may affect the ability of dietary fiber to reduce diabetes incidence in these groups. Results from this study indicate that some degree of protection against diabetes may be achieved through food choices even after taking into account body weight. However, the apparent protective effect of fiber, in particular from grains, against diabetes was primarily limited to those in the top category of intake, indicating the possibility of a threshold effect. Given the high Mg content of grains (8), food with a high fiber content may be protective against diabetes through a Mg-related mechanism.

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