Glycemic Index, Glycemic Load, and Cereal Fiber Intake and Risk of Type 2 Diabetes in US Black Women

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Background: Previous studies of carbohydrate quality and risk of type 2 diabetes mellitus have yielded inconsistent findings. Because diet is in part culturally determined, a study of dietary factors in US black women is of interest.

Methods: We used data from the Black Women’s Health Study, a prospective cohort study of 59,000 US black women, to examine the association of glycemic load, glycemic index, and cereal fiber with risk of type 2 diabetes. Diet was assessed at baseline in 1995 with a modified version of the National Cancer Institute–Block food frequency questionnaire.

Results: During 8 years of follow-up, there were 1938 incident cases of diabetes. Cox proportional hazards models were used to estimate incidence rate ratios (IRRs) for quintiles of dietary factors, while controlling for lifestyle and dietary factors. Glycemic index was positively associated with the risk of diabetes: the IRR for the highest quintile relative to the lowest was 1.23 (95% confidence interval [CI], 1.05-1.44). Cereal fiber intake was inversely associated with risk of diabetes, with an IRR of 0.82 (95% CI, 0.70-0.96) for the highest vs lowest quintiles of intake. Stronger associations were seen among women with a body mass index (calculated as weight in kilograms divided by height in meters squared) lower than 25: IRRs for the highest vs lowest quintile were 1.91 (95% CI, 1.16-3.16) for glycemic index (P value for interaction, .12) and 0.41 (95% CI, 0.24-0.72) for cereal fiber intake (P value for interaction, .05).

Conclusion: Increasing cereal fiber in the diet may be an effective means of reducing the risk of type 2 diabetes, a disease that has reached epidemic proportions in black women.

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The prevalence of type 2 diabetes mellitus in the United States has increased to epidemic proportions.¹ Incidence rates are higher in black than in white individuals, and black women have twice the incidence rate of white women.² Modifiable lifestyle factors, such as obesity and physical activity, play a major role in the development of type 2 diabetes.³,⁴ Dietary factors have also been implicated in the etiology of the disease, but their exact role is not clear.

See also page 2310

Metabolic studies have revealed that carbohydrates from different foods vary in the rate of absorption and in effects on blood glucose and insulin levels, indicating that various sources of carbohydrate intake produce different glycemic responses. Results from previous studies of the effects of glycemic load (GL) and glycemic index (GI), 2 measures of glycemic response to foods,⁵,⁶ on risk of diabetes have been inconsistent.⁷-¹¹ Cereal fiber is inversely associated with the risk of diabetes in most studies but has not been adequately studied in a large sample of black women.¹² Because diet varies across ethnic groups, a study of diet in US black women is of great interest. Our aim was to examine the association of GI, GL, and cereal fiber intake with the risk of type 2 diabetes in a cohort of US black women.

STUDY POPULATION

The Black Women’s Health Study (BWHS) is an ongoing prospective follow-up study of black women in the United States.¹³ The study began in 1995, when women aged 21 to 69 years were enrolled through postal questionnaires mailed to subscribers of Essence magazine, members of several professional organizations...
tions, and friends and relatives of early respondents. The women were from across all regions of the United States. The baseline questionnaire collected information on demographics, medical and reproductive history, weight, diet, smoking, and physical activity, and other factors.

After the exclusion of women whose addresses were judged to be invalid, 59,000 women have been followed through biennial postal questionnaires. The follow-up questionnaires collect updated information on weight, smoking, physical activity, incident disease, births, and other factors. Follow-up has been complete for approximately 80% of the baseline cohort for each questionnaire cycle.

The present analyses are based on follow-up from 1995 to 2003. We excluded women if they reported diabetes (n=2785) or gestational diabetes (n=665) at baseline; if they reported cancer (n=1165) or cardiovascular disease (n=809) at baseline (because they may have modified their diet after their diagnosis); if they were pregnant at baseline (n=956); if they were younger than 30 years at the end of follow-up (n=1960); if data on body mass index (BMI) (calculated as weight in kilograms divided by height in meters squared) was missing at baseline (n=472); if they did not complete the dietary questionnaire or left more than 10 dietary questions blank (n=2069); if they had implausible energy intake values (<500 or >3800 kcal; n=2997); or if they had implausibly low GL values (<45; n=3867). After these exclusions, the final analysis cohort consisted of 40,078 women.

CASE DEFINITION
Each follow-up questionnaire asked about physician-diagnosed diabetes during the previous 2 years. Incident cases of type 2 diabetes were ascertained from the 1997, 1999, 2001, and 2003 follow-up questionnaires. To eliminate possible cases of type 1 diabetes, we excluded 76 cases in which diabetes was diagnosed before age 30 years, leaving 1938 incident cases.

The accuracy of self-reported diabetes in the BWHS cohort was assessed among a random sample of 424 participants who reported having been diagnosed as having diabetes. They were mailed a medical release form and were asked for permission to contact their physicians. Once informed consent was obtained, the physician was mailed a questionnaire that asked about the diagnosis of diabetes, year of diagnosis, diagnosis method, and medication use. Of the 424 women who were sent a medical release, 183 (43%) returned signed releases. Physician questionnaires were obtained for 142 women (78%). The remaining physicians did not respond to our requests. The diagnosis of type 2 diabetes was confirmed for 135 of the 142 women (95%). Of the 7 unconfirmed cases, 2 were classified as type 1 diabetes, 3 were classified as metabolic syndrome, 1 involved steroid-induced diabetes, and 1 did not involve diabetes. Of the 142 participants for whom physician questionnaires were obtained, 107 reported taking medications for diabetes and 35 did not report taking any medications. Physician questionnaires confirmed the diagnosis of type 2 diabetes in 101 of the 107 participants (94%) who reported taking medications and in 34 of the 35 participants (97%) who did not report taking medications for diabetes. Thus, BWHS participants reported physician-diagnosed diabetes with a high level of specificity, whether or not they took medications for treatment of diabetes.

DIETARY MEASUREMENT
Diet was assessed at baseline in 1995 with a 68-item modified version of the short National Cancer Institute (NCI)-Block food frequency questionnaire (FFQ).14 We modified the FFQ to include food items specific to a black population based on write-in items from our pilot study. For each food, a common portion size was specified and the participant was asked to fill in how often she had consumed the food in the past year and the portion size of the food. The portion sizes used were small, medium, and large, with the small size being half of the medium and the large being one and a half times the medium size. The responses for frequency of consumption ranged from “never” to “<1 per month” to “2 or more per day.”

The FFQ was validated using a 3-day food diary and up to three 24-hour dietary recalls among a sample of 408 BWHS participants.15 Comparisons of the FFQ data with the diaries and recalls indicated satisfactory agreement, of about the same magnitude as in studies of other populations, for fat, protein, carbohydrate, dietary fiber, calcium, iron, vitamin C, folate and beta carotene: the correlation coefficients (energy adjusted and deattenuated) ranged from 0.5 to 0.8.

For each participant, the overall dietary GI was calculated by summing the products of the carbohydrate content per serving of the food times its GI times the mean number of servings of food per day.16 Each unit of dietary GL corresponds to the equivalent of 1 g of carbohydrate from glucose. The values of GI and carbohydrate content for the food items were obtained using standard databases.17 The overall dietary GI for each participant was calculated by dividing the dietary GL by the total amount of daily carbohydrate intake.17 That is, the overall dietary GI is the weighted mean of the GI of all carbohydrate-containing foods, with the weight being the amount of carbohydrates consumed.

Food analysis data from the US Department of Agriculture was used to obtain cereal fiber content for each ingredient for all grain-containing foods. Cereal fiber content per 100 g of food was calculated after taking into account the recipe and changes due to cooking methods for the specific food item. The cereal fiber intake for each participant was then calculated by summing the products of cereal fiber per 100 g times the grams of food per serving times the number of servings of food per day.

STATISTICAL ANALYSIS
Cox proportional hazards models were used to calculate incidence rate ratios (IRR), also known as hazard ratios, and 95% confidence intervals (CIs).18 The IRRs for diabetes were calculated for quintiles of each dietary measure relative to the lowest quintile. Person-years were calculated from the year of return of the 1995 questionnaire to the year of diagnosis of type 2 diabetes, loss to follow-up, death, or end of follow-up (March 2003), whichever came first. Dietary variables were adjusted for energy using the residuals method19 and categorized into quintiles based on their distribution. Covariates were included in the Cox regression model if the literature supported their role as confounders or if including them in the model changed the IRR by 10% or more. Confounders included in the regression models were age (continuous), BMI (<25, 25-29, 30-34, 35-39, and ≥40), family history of diabetes, cigarette smoking (nonsmokers, <15, 15-25, and ≥25 cigarettes per day), energy intake (quintiles), total fat intake (quintiles), and protein intake (quintiles). We estimated IRRs for the association of a particular dietary factor with the incidence of type 2 diabetes in 3 models: the first included age; the second added personal factors such as BMI, energy intake, family history of diabetes, cigarette smoking, and physical activity; and the third added other dietary factors. Variables not found to be confounders included alcohol intake, magnesium intake, history of hypertension, history of high blood cholesterol level, and education. Similar results were obtained with and without en-
GL, .06). Glycemic index was positively associated with the lowest quintile (0.98-1.51) for the highest quintile of GL intake relative to the lowest quintile of cereal fiber intake. The IRRs for the highest quintile of GI vs the lowest were 1.91 (95% CI, 1.05-1.44) for those with a BMI lower than 25 and 0.88 (95% CI, 0.70-0.96). In subgroup analysis of cases reporting diabetes medication use, similar results were obtained for GL, GI, and cereal fiber intake.

When we repeated the analyses stratifying by BMI category (Table 3), the associations were present both among women with a BMI lower than 25 and among those with a BMI of 25 or greater (overweight or obese) but were stronger in the thinner women. For example, the IRRs for the highest quintile of GI vs the lowest were 1.91 (95% CI, 1.16-3.16) for those with a BMI lower than 25 and 1.19 (95% CI, 1.01-1.40) for those with a BMI of 25 or greater (P value for interaction,.12). Similarly, for cereal fiber intake, the IRRs were 0.41 (95% CI, 0.24-0.72) for those with a BMI lower than 25 and 0.88 (95% CI, 0.74-1.04) for those with a BMI of 25 or greater (P value for interaction,.05).

In the present study, GI and GL were positively associated with risk of type 2 diabetes in US black women, and cereal fiber intake was inversely associated. The associations were present among both overweight women and those who were not overweight. There was an almost 2-fold increase in risk for those in the highest quintile of GI and a 59% decrease for those in the highest quintile of cereal fiber intake relative to the lowest in women with a BMI lower than 25. 

**Table 1. Baseline Characteristics by Quintiles of Glycemic Load, Glycemic Index, and Cereal Fiber Intake in the BWHS (1995-2003)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Glycemic Load, Quintile</th>
<th>Glycemic Index, Quintile</th>
<th>Cereal Fiber Intake, Quintile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Personal characteristics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median age, y</td>
<td>38.0</td>
<td>38.0</td>
<td>35.0</td>
</tr>
<tr>
<td>¥15 Cigarettes/d, %</td>
<td>15.4</td>
<td>10.5</td>
<td>10.5</td>
</tr>
<tr>
<td>Alcohol use, ¥7 drink/wk, %</td>
<td>12.9</td>
<td>3.6</td>
<td>3.0</td>
</tr>
<tr>
<td>Vigorous physical activity, ¥5 h/wk, %</td>
<td>11.1</td>
<td>13.4</td>
<td>18.2</td>
</tr>
<tr>
<td>Family history of diabetes, %</td>
<td>40.0</td>
<td>36.6</td>
<td>36.1</td>
</tr>
<tr>
<td>BMI, %&lt;30</td>
<td>35.1</td>
<td>26.7</td>
<td>28.4</td>
</tr>
<tr>
<td>Dietary intakes, mean ± SD</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Carbohydrates, % of energy</td>
<td>41.5±5.9</td>
<td>50.7±4.2</td>
<td>59.8±6.8</td>
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<tr>
<td>Fat, % of energy</td>
<td>41.8±6.2</td>
<td>34.2±4.6</td>
<td>26.9±6.2</td>
</tr>
<tr>
<td>Protein, % of energy</td>
<td>16.6±3.4</td>
<td>14.9±2.7</td>
<td>13.2±3.4</td>
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<td>Total fiber intake, g/d&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.2±3.4</td>
<td>11.7±3.7</td>
<td>12.8±5.0</td>
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<tr>
<td>Magnesium intake, g/d&lt;sup&gt;a&lt;/sup&gt;</td>
<td>191±47</td>
<td>208±47</td>
<td>223±68</td>
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<td>Glycemic load&lt;sup&gt;a&lt;/sup&gt;</td>
<td>77±14</td>
<td>109±29</td>
<td>149±21</td>
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<td>Glycemic index&lt;sup&gt;a&lt;/sup&gt;</td>
<td>45.9±5.5</td>
<td>49.9±5.3</td>
<td>56.3±8.2</td>
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<tr>
<td>Cereal fiber intake, g/d&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.9±1.7</td>
<td>4.1±1.9</td>
<td>5.9±3.8</td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); BWHS, Black Women’s Health Study.

<sup>a</sup>Energy adjusted using the residuals method.

**RESULTS**

Table 1 displays the distribution of lifestyle and dietary factors by quintiles of GL, GI, and cereal fiber intake. Women with high-GL diets were more physically active, had a lower prevalence of obesity, and reported lower cigarette and alcohol use compared with women with low GL diets. Glycemic load was also positively associated with higher GI and higher intake of carbohydrate, magnesium, fiber, and cereal fiber and inversely associated with total fat and protein intake. Women with high-GI diets reported lower cigarette use and higher cereal fiber intake. Higher cereal fiber intake was associated with higher physical activity, lower cigarette and alcohol use, higher intake of carbohydrates, protein, fiber, and magnesium, and lower intake of fats.

During 123 499 person-years of follow-up, there were 1938 new cases of type 2 diabetes. Glycemic load was inversely associated with risk of diabetes in the age-adjusted model (Table 2). This inverse association disappeared after adjustment for BMI, energy intake, family history of diabetes, cigarette smoking, and physical activity. Further adjustment for cereal fiber intake, total fat intake, and protein intake yielded an IRR of 1.22 (95% CI, 0.98-1.51) for the highest quintile of GL intake relative to the lowest quintile (P value for trend across quintile of GL, .06). Glycemic index was positively associated with diabetes risk in all 3 models (Table 2) (P value for trend,.001). In the multivariable model that included dietary factors, the IRR for the highest quintile of GI relative to the lowest was 1.23 (95% CI, 1.05-1.44). Cereal fiber intake was inversely associated with diabetes risk in all 3 models (Table 2) (P value for trend,.01). The IRR for the highest quintile of cereal fiber intake relative to the lowest was 0.82 (95% CI, 0.70-0.96). In subgroup analysis of cases reporting diabetes medication use, similar results were obtained for GL, GI, and cereal fiber intake.

**COMMENT**

In the present study, GI and GL were positively associated with risk of type 2 diabetes in US black women, and cereal fiber intake was inversely associated. The associations were present among both overweight women and those who were not overweight. There was an almost 2-fold increase in risk for those in the highest quintile of GI and a 59% decrease for those in the highest quintile of cereal fiber intake relative to the lowest in women with a BMI lower than 25.
Metabolic evidence suggests 2 possible mechanisms by which high GI foods can increase the risk of type 2 diabetes. First, a high-GI food produces a relatively high blood glucose concentration and a high-insulin demand. This increased insulin demand over time can result in loss of pancreatic function and eventually lead to glucose intolerance and diabetes. Second, high-GI foods can directly cause insulin resistance due to an increased production of postprandial fatty acids.

Two large cohort studies found a positive association of type 2 diabetes with both GI and GL. Two other studies did not. Most of the women in these studies were white. To our knowledge, the present study is the first large follow-up study to examine an association between GI and GL and type 2 diabetes in black women.

In the present study, risk of diabetes was statistically significantly associated with GI but not with GL. It can
be difficult to study GL because of its high correlation with total carbohydrate intake. In our study, cereal fiber intake increased with quintiles of GL, since even whole grains (a major source of cereal fiber) contribute to the GL. In addition, women in the higher quintiles of GL reported lower cigarette and alcohol use, more physical activity, lower BMI, and lower fat intake. The reason is that health-conscious women tend to follow the low-fat, high-carbohydrate diet. This may explain the initial protective effect observed for GL. However, once we adjusted for all the aforementioned factors, the direction of the association changed.

We were also able to examine the effect of these dietary factors in an analysis stratified by BMI category. A metabolic study of fasting plasma triacylglycerol levels in 185 healthy women indicated that GL was more strongly associated with triacylglycerol levels in women with a BMI greater than 25, suggesting that the adverse effects of a high-carbohydrate diet may increase with an individual's degree of underlying insulin resistance.6,20 However, the 2 previous studies of GL, GI, and cereal fiber intake in relation to type 2 diabetes that stratified by BMI did not find a significant interaction of BMI category and the dietary factor.7,20 In fact, one study showed a higher relative risk for GL in the lower BMI group.7 This is consistent with our finding of a stronger association of GL and cereal fiber intake in women with a BMI lower than 25. One possible explanation is that obesity is such a strong risk factor for type 2 diabetes that it may be difficult to detect the effects of other factors in obese women. It is also possible that the differences in the IRRs in those with a BMI lower than 25 and a BMI of 25 or greater may be simply due to chance. These results should not be taken to mean that overweight and obese women should not reduce their consumption of refined carbohydrates for prevention of diabetes.

Fiber has been shown to decrease postprandial glucose and insulin concentrations in individuals with and without diabetes.21 The effect of fiber is attributed to soluble fiber that creates a gel-like substance in the stomach and slows the absorption of food. However, most studies have found that insoluble fiber and not soluble fiber is inversely related to diabetes. Insoluble fiber may lower the amount of carbohydrates absorbed, leading to a lower insulin demand and therefore a lower risk of diabetes.12 Previous studies on cereal fiber have all indicated that increased cereal fiber intake is inversely associated with the risk of diabetes in both men and women.7,12 The only study of cereal fiber and diabetes that included appreciable numbers of African Americans found an inverse association, but the association was not statistically significant.10 Our study, with greater statistical power, shows that cereal fiber intake is inversely associated with the risk of diabetes in black women.

Food frequency questionnaires have been used to measure diet in prospective studies with some success.22 Our validation study of the FFQ used in the present study indicated that dietary intake measured by the FFQ was significantly correlated with diet measured using diet recalls and diaries.18 A main strength of this study is the prospective study design, which eliminates the potential for recall bias. The follow-up rates for each biennial questionnaire period were high and reduced the likelihood of bias resulting from differential loss related to both exposure and outcome. Important confounding factors were taken into account in the analysis. Body mass index, a strong risk factor for type 2 diabetes in this population and the strongest confounder of the associations found in our study, was closely controlled. The associations of GI and cereal fiber intake with risk of type 2 diabetes were present even in the leanest women (BMI <25), among whom there would be minimal residual confounding by BMI.

The identification of cases of diabetes in the present study was based on self-reports. A validation study indicated that diabetes was reported with a high degree of specificity, whether or not diabetes medications were used. We cannot rule out the possibility that some women with undiagnosed diabetes were misclassified as noncases, but the prevalence of undiagnosed disease was likely to be low. The prevalence of undiagnosed diabetes among US black women ranged from 1.7% in those aged 20 to 39 years to 8.5% in those aged 60 to 74 years based on national survey data from the Third National Health and Nutrition Examination Survey (1988-1994).23 Because diabetes is known to disproportionately affect the US black population, it seems likely that BWHS participants were screened for the disease during the course of regular checkups. In general, access to health care is good among BWHS participants, with 93% reporting that they had health insurance in 1997, 91% reporting having received a Papanicolaou test in the past 2 years, and 98% reporting that they had visited a physician or hospital in the past 2 years. Therefore, it is unlikely that undiagnosed diabetes is a major problem.

The BWHS participants are from across the United States, and 97% of the participants have a high school or higher level of education. Among the US black female population of the same ages, 83% have at least a high school education.24 In this respect, our results should be applicable to most US black women, except the approximately 17% who have not completed high school.

Our results indicate that black women can reduce their risk of diabetes by eating a diet that is high in cereal fiber. In the BWHS, women in the highest quintile of cereal fiber intake (≥5.9 g/d) had an 18% reduction in risk of type 2 diabetes. Incorporating fiber sources into the diet is relatively easy: a simple change from white bread (2 slices provides 1.2 g of fiber) to whole wheat bread (2 slices provides 3.8 g of fiber) or substituting a cup of raisin bran (5.0-8.0 g of fiber) or oatmeal (4.0 g of fiber) for a cup of corn chex (0.5 g of fiber) or rice chex (0.3 g of fiber) will move a person from a low fiber intake category to a moderate intake category, with a corresponding 10% reduction in risk.25 The substitution of these whole grain foods may have additional benefits owing to other nutrient components such as magnesium.26,27 The findings from this study have implications for primary prevention of a disease that has reached epidemic proportions among black women.
Author Contributions: Dr Krishnan had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Krishnan, Rosenberg, Cupples, and Palmer. Acquisition of data: Rosenberg and Palmer. Analysis and interpretation of data: Krishnan, Rosenberg, Singer, Hu, Djoussé, Cupples, and Palmer. Drafting of the manuscript: Krishnan. Critical revision of the manuscript for important intellectual content: Krishnan, Rosenberg, Singer, Hu, Djoussé, Cupples, and Palmer. Statistical analysis: Krishnan, Djoussé, and Cupples. Obtained funding: Rosenberg and Palmer. Administrative, technical, and material support: Singer. Study supervision: Palmer.

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REFERENCES