Low dietary fiber and high protein intakes associated with newly diagnosed diabetes in a remote aboriginal community\textsuperscript{1-3}

Thomas MS Wolever, Safa Hamad, Joel Gittelsohn, Joe Gao, Anthony JG Hanley, Stewart B Harris, and Bernard Zinman

ABSTRACT The high prevalence of diabetes mellitus in North American aboriginal populations may be due to recent changes in lifestyle, including the adoption of a high-fat, low-fiber diet. To determine whether fat or fiber intakes were associated with new cases of diabetes, we studied 72\% (728/1018) of residents aged \textgreater{} 9 years from a remote aboriginal community in northern Ontario using the 75-g oral-glucose-tolerance test and 24-h dietary recall. The mean fat intake of this population (36\% of energy) was typical for North America, but fiber intake (1.2 g/MJ) was very low. Logistic-regression analysis, adjusted for age, sex, and body mass index, showed that a 1-SD increase in fiber intake reduced the risk of having diabetes by 39\% (P = 0.026) whereas the same increase in protein intake increased the risk by 38\% (P = 0.027). There was no significant effect of energy, fat, starch, or simple sugars. These data support Trowell's original dietary-fiber hypothesis that "...dietary fiber depleted starchy foods are conducive to the development of diabetes mellitus in susceptible human genotypes."  


KEY WORDS Dietary fiber, diabetes mellitus, protein, Ontario, Sandy Lake Health and Diabetes Project, Amerindians

INTRODUCTION

Non-insulin-dependent diabetes mellitus (NIDDM) has become one of the leading public health problems among aboriginal people in the United States, Canada, and other countries (1). The prevalence of NIDDM in Amerindians is three to five times greater than that of the general North American population, with the Pima Indians of Arizona having the highest rate in the world (2). It is generally considered that the high rate of NIDDM in these populations is due to recent profound social, environmental, and lifestyle changes, including increased fat intake (3) and reduced physical activity (4), acting on a susceptible genotype (1).

The Sandy Lake Health and Diabetes Project began in 1992, with the overall aim of developing effective strategies for preventing diabetes in the community. The project was initiated at the request of the Sandy Lake Band Council, which was involved in the development and promotion of the project in the community. The specific aims of the project were to determine the prevalence of diabetes and impaired glucose tolerance in the community; to identify anthropometric, metabolic, and lifestyle characteristics associated with abnormal glucose tolerance; and to develop culturally appropriate and effective strategies to prevent diabetes and its complications (5). We found that the age-adjusted prevalence rate of NIDDM in the community, 26\%, was among the highest in the world (6).

The purpose of the present study was to determine whether any associations exist between nutrient intake and the prevalence of newly diagnosed cases of diabetes. The diet in Sandy Lake contains 36\% of energy from fat and 22\% from simple sugars (7), similar to the typical North American diet. However, mean fiber intake, 1.2 g/MJ, is only one-half that of the North American average, which is of particular interest in light of the dietary-fiber hypothesis published previously (8). Thus, our hypothesis was that high fat, high sugar, and low fiber intakes would be associated with newly diagnosed cases of diabetes.

The purpose of this paper was to determine whether there was any relation between diet and newly diagnosed diabetes. Subjects known to have diabetes were excluded from analysis because, as part of their diabetes management, they would have received advice about following an energy-reduced, low-fat diet, which may have resulted in a change in their reported dietary habits as assessed by 24-h recall. We showed previously that age, sex, or both influenced the intakes of energy and many nutrients (7).

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METHODS

The community studied was Sandy Lake, Ontario, which is typical of the 28 scattered aboriginal communities in the 385 000 km² in northwestern Ontario. Approximately 14 000 registered Algonquin-speaking Cree and Ojiway natives live in this vast area, which extends from the town of Sioux Lookout in the southeast to the border with Manitoba in the west and Hudson’s Bay in the north. Sandy Lake, situated ~800 km northwest of Lake Superior, was appropriate for this study because of its isolation (the only reliable method of transport is by air; with several daily flights made to Sioux Lookout, 400 km to the southeast), minimal immigration and emigration, and the strong support for the study from the Chief and Band Council. Detailed information about the community and the aims and design of the study are described elsewhere (5). The study was approved by the Ethics Committee of the University of Toronto.

All registered members of the Sandy Lake or other bands who had lived in Sandy Lake for ≥ 6 mo of the previous year were eligible for participation. Volunteers aged > 9 y with no previous diagnosis of diabetes underwent a 75-g oral-glucose-tolerance test (OGTT) (Glucodex; Rougier Inc, Chambly, Canada) after an overnight fast of ≥ 8 h. Blood samples taken after fasting and 2 h after the OGTT were centrifuged (600 × g, 10 min, 4 °C) on site to remove the plasma, which was frozen overnight at −20 °C before being shipped to the Sioux Lookout Zone Hospital laboratory (Sioux Lookout, Canada) for glucose analysis by a hexokinase method with a Cobas Mira autoanalyzer (Roche Diagnostics, Mississauga, Canada). In accordance with World Health Organization criteria (9), the diagnosis of diabetes was made if fasting plasma glucose was ≥ 7.8 mmol/L or if plasma glucose was ≥ 11.1 mmol/L 2 h after the OGTT. Height and weight were measured with the volunteers dressed in light clothing or an examination gown. Body mass index (BMI) was calculated as weight (in kg) divided by height squared (in m).

Between the time that fasting and 2-h blood samples were taken, various questionnaires were administered by trained surveyors from the community, including a 24-h recall. Volunteers were asked to report all foods consumed during the past 24 h. They were prompted to include the type and amount of added fat, sugar, and snacks. Portion sizes were assessed with measuring cups and spoons, three-dimensional food models, and a set of validated two-dimensional models (10). Recipes for traditional and other homemade dishes were obtained from the person who prepared them. The 24-h recalls were conducted in English or Oji-Cree, depending on the preference of the respondent; however, the information was recorded in English.

Copies of completed 24-h recalls were sent to the University of Toronto for coding with a dietary database derived from the Condensed Canadian Nutrient File (11). Traditional foods not included in this file were added to the database with their nutrient content derived from other sources (D Brulé, Nutrition Research Division, Health Protection Branch, Health and Welfare Canada; personal communication, 1993). Values for dietary fiber were modified and values for simple sugars taken from food tables (12), from manufacturer’s information, or derived from dietary fiber analysis by standard methods were added to the database (13). Values for carbohydrate were adjusted to reflect available carbohydrate, i.e., total carbohydrate minus dietary fiber. Starch was taken to be the difference between available carbohydrate and simple sugars plus oligosaccharides. Energy intake is given in kJ; fat, protein, and carbohydrate are expressed as a percentage of energy; dietary fiber is expressed in g/MJ, and vitamins are expressed as total daily intake.

Data were managed and analyzed in the Division of Clinical Epidemiology, Samuel Lunenfeld Research Institute, Mount Sinai Hospital, University of Toronto. The SIR database management software package (14) was used for data entry and management on a Digital MicroVax computer (Digital Equipment of Canada Ltd, Markham, Canada). Statistical analysis was carried out by using the SAS software package (15). Logistic-regression analysis was used to determine the association between nutrient intakes and the risk of having newly diagnosed diabetes. Each relevant nutrient was considered separately in a model adjusted for age, sex, and BMI. The odds ratio (OR), an unbiased estimate of the relative risk, was calculated by exponentiating the β coefficient of the regression model. ORs refer to the relative risk associated with a 1-SD increase in intake of a given nutrient based on the distribution among nondiabetic subjects. Relations were considered significant if P < 0.05.

RESULTS

A total of 728 eligible participants aged > 9 y were enrolled, representing a participation rate of 72%. Of the 728 participants, 718 (98.6%) provided a complete 24-h dietary recall; 76 of them were known to have diabetes and were excluded. Of the remaining 642 subjects, 12 (1.9%) were excluded because of incomplete data; thus, complete data were available for 630 individuals with no history of diabetes, of whom 50 (7.9%) were found to have diabetes by an OGTT (Table 1). In a logistic-regression model including age, sex, and BMI, there was no significant association between sex and diabetes (P = 0.18), but both age (per year of age: OR = 1.04, P < 0.0001) and BMI (per BMI unit: OR = 1.18, P < 0.0001) were significantly associated with diabetes.

Mean unadjusted nutrient and fiber intakes in the subjects with newly diagnosed diabetes and in those without diabetes

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Sex, age, and body mass index of the study population</th>
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<tbody>
<tr>
<td></td>
<td>No diabetes</td>
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<tr>
<td>Males (n)</td>
<td>249</td>
</tr>
<tr>
<td>Age (y)</td>
<td>27.6 ± 14.8 (10–79)</td>
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<tr>
<td>Body mass index (kg/m²)</td>
<td>24.9 ± 4.9 (15.4–35.7)</td>
</tr>
<tr>
<td>Females (n)</td>
<td>331</td>
</tr>
<tr>
<td>Age (y)</td>
<td>26.2 ± 14.2 (10–79)</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>26.9 ± 6.1 (14.4–44.3)</td>
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<tr>
<td>All subjects (n)</td>
<td>580</td>
</tr>
<tr>
<td>Age (y)</td>
<td>26.8 ± 14.5 (10–79)</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>26.0 ± 5.7 (14.4–44.3)</td>
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¹ ± SD; range in parentheses.
are shown in Table 2. Subjects with newly diagnosed diabetes had significantly higher protein and significantly lower dietary fiber intakes than the nondiabetic population, but similar intakes of energy, total fat, saturated and polyunsaturated fat (not shown), carbohydrate, starch, sugars, calcium, vitamin A, vitamin C, and folate (Table 2). Logistic regression analysis—adjusted for age, sex, and BMI—showed that the effects of protein and fiber remained significant (Table 2). In this population, protein and fiber had opposite effects on the risk of having diabetes; a 1-SD increase in protein intake (7.2% of energy) was associated with a 38% increase in the risk of having diabetes (P = 0.027), whereas a 1-SD increase in fiber intake (0.7 g/MJ) reduced the risk of having diabetes by 39% (P = 0.026; Table 2). The effect of dietary fat was not significant regardless of whether fat intake was expressed as a percentage of energy (Table 2), grams per day (OR = 1.34, P = 0.057), or grams per day adjusted for energy intake by including energy in the regression model (OR = 1.20, P = 0.55).

DISCUSSION

The data show that high protein and low dietary fiber intakes were associated with an increased prevalence of newly diagnosed diabetes in Sandy Lake, independent of age, sex, and BMI. Previous studies on the relation between diet and diabetes have had inconsistent results. There was no significant effect of diet in a case-control study in Papua New Guinea (16). High fat intake was associated with diabetes in the San Luis Valley Diabetes Study (17), in second-generation Japanese Americans (18), and in Mexicans in San Antonio, TX, compared with those in Mexico City (19). High carbohydrate intake was associated with glucose intolerance in an elderly Dutch population (20). High energy-adjusted intakes of vegetable fat, potassium, calcium, and magnesium were associated with a reduced risk for diabetes in the Nurses' Health Study (21). No effect of diet was found in the Israel Ischemic Heart Disease Study (22), the Zutphen Study (23), or a study in Gothenburg, Sweden (24). When information on dietary fiber intake was available (17, 20, 21), it did not have a significant effect. However, recently, an extended follow-up of the Nurses' Health Study showed that the risk of developing diabetes in those in the highest quintile of fiber intake (24 g/d) was 0.78 times that in those in the lowest quintile (12 g/d) (P = 0.02) (25).

A major problem in doing studies of this nature is that it is virtually impossible to determine, with the same degree of accuracy as can be obtained with biochemical data, the true nutrient intake of the individuals in the study. Food intake varies markedly from day-to-day within individuals, so that a 24-h recall, the method used here, is unlikely to reflect an individual's long-term intakes (26). Obtaining dietary records for more than one day, or on more than one occasion, improves the reliability of the data. However, because of the low level of literacy in the study population, it was not feasible to collect 3-d diet records. The effect of inaccurate measures of nutrient intake is to reduce the chance of finding correlations between nutritional and biochemical variables (27). In addition, when significant relations are found, the real effects are likely to be stronger than those observed (27).

The lack of significant association between fat intake and diabetes surprised us, and may have been because nutrient intakes were expressed as a percentage of energy, which increases the ratio of intra- to interindividual variance, thus reducing the chance of finding significant correlations (27). Therefore, after completing the initial statistical analysis, we assessed the association between fat intake and diabetes when fat intake was expressed by weight (g/d) and when fat intake was adjusted for energy by including energy in the multivariate-regression model. The relation between fat intake (in g) and diabetes was nearly significant; however, when fat intake was adjusted for energy there was no such relation. In an examination of the relation between nutrient intakes and health outcomes, it is usually considered necessary to adjust for energy intake; however, there are several ways of doing this. Beaton et al (28) suggest that in exploring the relation between fat intake and obesity, different ways of adjusting fat intake for energy yield different results. The reason for this is not clear but could be because of subtle differences in the biological relevance of the different analyses, or because of differences in the error introduced by the different analyses. In two of the three examples Beaton et al used, adjustment of fat intake for

<table>
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<td>Nutrient intakes in subjects without diabetes and in those with newly diagnosed diabetes</td>
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<tr>
<td>Energy (kJ)</td>
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<tr>
<td>Protein (% of energy)</td>
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<tr>
<td>Total fat (% of energy)</td>
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<tr>
<td>Carbohydrate (% of energy)</td>
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<tr>
<td>Simple sugars (% of energy)</td>
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<tr>
<td>Starch (% of energy)</td>
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<tr>
<td>Fiber (g/MJ)</td>
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<tr>
<td>Calcium (mg)</td>
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<tr>
<td>Vitamin A (RE)*</td>
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<tr>
<td>Vitamin C (mg)</td>
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<td>Folate (mg)</td>
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1 Risk ± SD (unadjusted). 
2 Risk having diabetes associated with a 1-SD increase in intake based on distribution in nondiabetic subjects. 
3 Significantly different from no diabetes, P = 0.02. 
4 RE, retinol equivalents.
energy by including both fat and energy in the multivariate model resulted in a positive relation between fat intake and obesity, whereas expression of fat as a percentage of energy did not. In our study, however, these two ways of adjusting fat intake for energy resulted in similar ORs, neither of which was significant.

The pathogenesis of NIDDM is believed to be related to reduced insulin action, ie, insulin resistance (29), reduced insulin secretion (30), or both. Increased protein or fiber intakes could exacerbate either of these potential mechanisms. In many individuals, insulin resistance may be the predominant abnormality leading to NIDDM. The normal physiologic response to insulin resistance is increased insulin secretion, which maintains plasma glucose within the normal range. However, modest hyperinsulinemia increases insulin resistance (31). Thus, a vicious circle may ensue, resulting in ever-increasing degrees of insulin resistance and hyperinsulinemia. Ultimately, NIDDM develops when the ability to increase insulin secretion fails, possibly because of the effects on the β-cell of glucose toxicity or amyloid deposition. Amyloid is a protein that is secreted with insulin, accumulates within the islets of Langerhans, and ultimately damages the β-cells (32). Thus, increased insulin secretion may be associated with an increased rate of secretion and deposition of amyloid. Because dietary protein is known to stimulate insulin secretion (33), high protein intakes could increase the risk of developing diabetes in susceptible populations by enhancing insulin secretion with resulting effects on insulin resistance and amyloid deposition. Conversely, foods rich in dietary fiber tend to produce low blood glucose and insulin responses (34), possibly by reducing the rate of digestion and absorption of starch. Thus, increased fiber intake could be speculated to reduce insulin resistance and reduce the rate of amyloid deposition. In support of this, there is evidence that a diet containing slowly digested starch delays the development of insulin resistance in experimental animals (35). Also, a reduction in the rate of starch digestion with the use of the α-glucosidase inhibitor acarbose improves insulin sensitivity in humans with impaired glucose tolerance (36).

We conclude that these data support the original dietary-fiber hypothesis proposed by Hugh Trowell in 1975 that “…dietary fiber depleted starchy foods are conducive to the development of diabetes mellitus in susceptible human genotypes” (8).

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