Food-Insecure Dietary Patterns Are Associated With Poor Longitudinal Glycemic Control in Diabetes: Results From the Boston Puerto Rican Health Study

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OBJECTIVE

To determine whether dietary patterns associated with food insecurity are associated with poor longitudinal glycemic control.

RESEARCH DESIGN AND METHODS

In a prospective, population-based, longitudinal cohort study, we ascertained food security (Food Security Survey Module), dietary pattern (Healthy Eating Index–2005 [HEI 2005]), and hemoglobin A_{1c} (HbA_{1c}) in Puerto Rican adults aged 45–75 years with diabetes at baseline (2004–2009) and HbA_{1c} at $\sim$2 years follow-up (2006–2012). We determined associations between food insecurity and dietary pattern and assessed whether those dietary patterns were associated with poorer HbA_{1c} concentration over time, using multivariable-adjusted repeated subjects mixed-effects models.

RESULTS

There were 584 participants with diabetes at baseline and 516 at follow-up. Food-insecure participants reported lower overall dietary quality and lower intake of fruit and vegetables. A food insecurity*HEI 2005 interaction ($P < 0.001$) suggested that better diet quality was more strongly associated with lower HbA_{1c} in food-insecure than food-secure participants. In adjusted models, lower follow-up HbA_{1c} was associated with greater HEI 2005 score ($\beta = -0.01$ HbA_{1c} % per HEI 2005 point, per year, $P = 0.003$) and with subscores of total vegetables ($\beta = -0.09$, $P = 0.04$) and dark green and orange vegetables and legumes ($\beta = -0.06$, $P = 0.048$). Compared with the minimum total vegetable score, a participant with the maximum score showed relative improvements of HbA_{1c} of 0.5% per year.

CONCLUSIONS

Food insecurity was associated with lower overall dietary quality and lower consumption of plant-based foods, which was associated with poor longitudinal glycemic control.

Diabetes is a major public health problem, with over 25 million Americans affected (1). Vulnerable patients, such as those of Hispanic race/ethnicity and lower socioeconomic status bear a disproportionate share of diabetes morbidity and mortality (2).

Because reducing disparities in diabetes is a public health priority (2), identifying modifiable mechanisms linking vulnerability to poor health outcomes is an

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important research goal. One mechanism to explain the high burden of diabetes may be food insecurity, defined as "limited or uncertain availability of nutritionally adequate and safe foods or limited or uncertain ability to acquire acceptable foods in socially acceptable ways" (3). Cross-sectional studies have linked food insecurity to poor diabetes control (4–6). However, the mechanism of this association remains unclear. Some have suggested that food insecurity can lead to a "substitution effect" where cheaper, high calorie density foods, such as refined carbohydrates, fats, and oils, are substituted for more expensive foods such as fresh fruit and vegetables (7). However, although several studies have examined dietary patterns in a more general population (8–15), the detailed dietary pattern of food-insecure diabetic patients is less well established. The dietary pattern of food-insecure diabetic patients may differ from that of the overall food-insecure population because of dietary counseling, which is a key part of diabetes management, and diabetic patients' desire to eat more healthily (16). Further, whether the dietary patterns adopted by food-insecure diabetic patients are associated with poor longitudinal glycemic control is an important clinical question.

To address these issues, we undertook an investigation using longitudinal data from the Boston Puerto Rican Health Study, a population with a high burden of both diabetes and food insecurity. We tested the hypothesis that food insecurity among diabetic patients would be associated with adverse dietary patterns, and that these patterns would be associated with poor longitudinal glycemic control.

RESEARCH DESIGN AND METHODS

Setting and Study Sample

We used data from the Boston Puerto Rican Health Study. This ongoing, prospective, longitudinal study is designed to investigate social, environmental, and genetic risk factors for chronic illness and has been described in detail previously (17,18). Participants (age 45–75 years at baseline) were selected by stratified, neighborhood-based random sample around Boston, MA, and those who were unable to provide information due to medical illness, such as dementia, were excluded. This study's sample consists of all participants with diabetes (report of receiving oral diabetes medication, insulin, or fasting plasma glucose $\geq$126 mg/dL) (19,20). Baseline visits were conducted from 2004 to 2009, with a follow-up visit ~2 years later (2006–2012). Interviews were conducted in the home in English or Spanish according to the patient's preference. The institutional review board at Tufts Medical Center approved the study protocol, and all participants provided written informed consent.

Food Insecurity and Dietary Pattern

Whether a participant was a member of a food-insecure household was assessed using the 10 adult-referenced items of the U.S. Department of Agriculture's (USDA's) Food Security Survey Module (3,21). This module has been extensively validated in both English and Spanish and is used in reporting national rates of food insecurity. Following standard scoring (3,21), a participant who indicated three or more affirmative responses for his or her household was food insecure, as opposed to food secure. For exploratory analyses, we also subdivided food insecurity into the standard categories of "low food insecurity" (between three and five affirmative responses) and "very low food security" (greater than five affirmative responses).

Dietary pattern was assessed using the Healthy Eating Index–2005 (HEI 2005) (22), according to a method used in a previous study (23). First, dietary intake over the preceding 12 months was assessed with validated, semiquantitative food frequency questionnaires as part of an in-home interview. The HEI 2005 score was calculated according to the method recommended by the USDA Center for Nutrition Policy and Promotion. This score includes 12 subscores representing different food groups. A higher score represents greater consumption of "healthy" foods, such as leafy green vegetables, or less consumption of "unhealthy" foods, such as sugared drinks. All subscores are arranged such that a higher score represents more "healthy" dietary intake. The total score, which represents a sum of the subscores, ranges from 0 (least healthy) to 100 (most healthy). The subcomponents of the index are as follows: total fruit, whole fruit, total vegetables, dark green and orange vegetables and legumes, total grains, whole grains, milk, meat and beans, oils, saturated fats, sodium, and energy from SoFAAS (solid fats, alcoholic beverages, and added sugars).

Outcomes

To assess which dietary patterns were associated with food insecurity, we used the total HEI 2005 score and its subcomponents as outcomes for our analysis of dietary pattern. To examine longitudinal glycemic control, we examined hemoglobin A_{1c} (HbA_{1c}) concentration at both the baseline and return visit.

Covariates

Baseline data on sex, educational attainment (categorized as $\leq$5th grade, 5–9th grade, 9–12th grade or GED, some college or bachelor's degree, or some graduate school or higher), income-to-poverty ratio (which accounts for household size and year of measurement), smoking status (never, current, or former), and alcohol consumption (never, former, or current) were taken from the home interview. For glycemic medications, we constructed binary indicators for each for the following classes: metformin, sulfonylureas, thiazolidinediones, meglitinides, or insulin. Dipeptidyl peptidase-4 inhibitors were not commonly in use during this period. Information regarding physical activity was also collected, as were measurements to permit calculation of BMI, defined as weight in kilograms divided by height in meters squared.

Statistical Analysis

We first performed descriptive statistics and unadjusted analyses, stratified by dietary quality, using χ^2 tests for categorical variables and Wilcoxon tests for continuous variables, given their nonnormal distribution. We next tested the association of food insecurity and dietary pattern at baseline using Wilcoxon tests. Finally, we fit separate repeated-measures multivariable linear mixed-effects models (SAS PROC MIXED), using dietary patterns, as indicated by HEI score and subscores, as exposures, and adjusted for the covariates listed above and time between HbA_{1c} measurements in participants with diabetes. This allowed us to evaluate how change in HbA_{1c} over time was associated with baseline dietary pattern. The associations with total HEI represented our primary analyses. We then evaluated the relationships with HEI components as exploratory analyses to generate hypotheses about dietary pattern components and glycemic control. The covariates in these models were selected on the basis of prior work demonstrating their association with dietary pattern and/or glycemic control (4,13,16,22). SAS version 9.3 (SAS Institute, Cary, NC) was used for all analyses.

RESULTS

Of 1,499 participants who completed the baseline exam, 584 (39%) met the criteria for diabetes. At the repeat examination, 516 participants with diabetes remained. Included participants were largely female (70.4%), had less than a college education (87%), and had low income (mean ratio of household income to poverty level 1.21) (Table 1). Overall, 26% of included participants reported household food insecurity. Participants with lower dietary quality, defined as an HEI 2005 score less than the median of 73.7, were more likely to be younger, male, and current cigarette smokers and alcohol drinkers, compared with those with higher diet quality (Table 1).

There were several differences in dietary pattern between food-insecure and food-secure participants. Food-insecure participants reported lower overall dietary quality, and specifically diets lower in total fruit, whole fruit, total vegetables, and dark green and orange vegetables and legumes (Table 2). There were no significant differences in whole grains, saturated fats, sodium, or calories from SoFAAS. When examining the subdivided categories of food insecurity, the dietary patterns of respondents in households with both “low food security” and “very low food security” were nearly identical, with no significant differences for any pattern.

In unadjusted, longitudinal, mixed-effects models of glycemic control, participants reporting food insecurity had higher HbA_{1c} (difference between food insecure compared with secure = 0.3% [95% CI 0.7, −0.1]) but this difference was not statistically significant (P = 0.14). There was no difference in change in HbA_{1c} over time by food security status (P = 0.33). However, there was a significant difference in change in HbA_{1c} over time when looking at both food security status and dietary quality (total HEI 2005 score), with better diet quality associated with greater reduction in HbA_{1c} in food-insecure, compared with food-secure, participants (improvement in HbA_{1c} 0.02% [95% CI 0.02, 0.006] per HEI point per year greater in food-insecure participants; P value for interaction = 0.004).

In unadjusted models, several dietary patterns associated with food insecurity were also associated with poor glycemia. Higher total HEI 2005 score and

Table 1—Descriptive variables by dietary quality score

Characteristic	Overall (*n* = 584)	Lower diet quality (*n* = 287)	Higher diet quality (*n* = 287)	*P* value*
Age (years)	58.9 (7.3)	57.2 (7.1)	60.5 (7.0)	<0.0001
Female	70.4	64.1	76.7	0.001
Education				0.78
≤5th grade	26.9	24.7	29.3	
5–9th grade	25.6	26.8	24.4	
9–12th/GED	33.8	34.8	33.1	
College	12.5	12.5	11.9	
Graduate school	1.2	1.1	1.4	
Income-to-poverty ratio	1.21 (1.09)	1.20 (1.12)	1.20 (1.06)	0.62
Food insecure	26.0	29.6	23.0	0.07
Smoking status				0.0002
Never	47.4	44.3	50.2	
Former	32.0	27.9	35.9	
Current	20.6	27.9	14.0	
Alcohol use				0.0005
Never	31.4	26.3	37.3	
Former	35.1	33.0	36.6	
Current	33.5	40.7	26.2	
Glycemic medications				
Metformin	54.6	54.4	54.4	0.99
Sulfonylurea	31.0	28.6	33.8	0.18
Thiazolidinediones	19.2	19.9	18.8	0.75
Insulin	26.7	23.3	29.6	0.09
Physical activity score	30.9 (4.3)	30.1 (4.8)	30.6 (3.7)	0.48
BMI (kg/m^2)	33.6 (6.9)	33.5 (6.8)	33.7 (6.9)	0.97
HbA_{1c} at baseline	8.4 (2.0)% [68 (21.9) mmol/mol]	8.3 (2.0)% [67 (20.8) mmol/mol]	8.4 (1.9)% [68 (21.9) mmol/mol]	0.16
HbA_{1c} at follow-up	7.9 (1.7)% [63 (18.6) mmol/mol]	8.0 (1.9)% [64 (21.9) mmol/mol]	7.8 (1.5)% [62 (16.4) mmol/mol]	0.10

Data are presented as % or mean (SD), unless indicated otherwise. Lower diet quality represents HEI 2005 score <72 (median). Higher diet quality represents HEI 2005 score ≥72. *From χ^2 or Wilcoxon test.

Table 2—HEI 2005 scores by food security status

	Overall	Food secure	Food insecure	
HEI	Median (IQR)	Median (IQR)	Median (IQR)	*P* value*
Total	74.1 (67.3–78.8)	74.7 (67.4–79.3)	72.4 (67.2–77.4)	**0.048**
Total fruit	3.1 (1.9–5.0)	3.3 (1.4–5.0)	2.9 (1.6–4.6)	**0.03**
Whole fruit	3.1 (1.9–5.0)	3.3 (2.0–5.0)	2.6 (1.6–4.6)	**0.01**
Total vegetables	4.2 (3.4–4.0)	4.4 (3.5–5.0)	4.0 (3.0–4.8)	**0.005**
Dark green and orange vegetables and legumes	2.6 (1.6–4.2)	2.8 (1.7–4.3)	2.2 (1.2–3.7)	**0.007**
Total grains	5.0 (4.3–5.0)	5.0 (4.3–5.0)	5.0 (4.5–5.0)	**0.01**
Whole grains	1.2 (0.5–2.4)	1.2 (0.5–2.5)	1.0 (0.5–2.2)	0.42
Milk	5.8 (3.8–8.4)	5.9 (3.9–8.8)	5.6 (3.2–7.8)	0.11
Meat and beans	10.0 (10.0–10.0)	10.0 (10.0–10.0)	10.0 (10.0–10.0)	0.82
Oils	10.0 (8.5–10.0)	10.0 (8.5–10)	10.0 (8.7–10.0)	0.57
Saturated fats**	8.4 (6.3–9.3)	8.4 (6.3–9.3)	8.4 (6.6–9.3)	0.73
Sodium**	5.4 (3.8–6.8)	3.7 (2.0–5.4)	3.9 (2.0–5.5)	0.94
Energy from SoFAAS	19.1 (15.6–20.0)	19.3 (15.6–20.0)	19.0 (16.4–20.0)	0.90

Boldface indicates $P < 0.05$. *From Wilcoxon test. **Higher score represents lower consumption.

higher scores on the subcomponents of total vegetable score and dark green and orange vegetables and legumes score at baseline were all associated with significantly lower subsequent HbA_{1c} (Table 3). Also associated with lower glycemia were higher (representing less consumption) scores on the saturated fats and energy intake from SoFAAS subscores. In models adjusted for age, sex, education, income-to-poverty ratio, glycemic medications, alcohol use, smoking, physical activity, and BMI, total HEI 2005 score and the subscores of total vegetables, dark green and orange vegetables and legumes, saturated fats, and energy intake from SoFAAS remained significant (Table 3). The β coefficients from these models represent change in HbA_{1c} per point on the HEI score per year, with a negative β coefficient denoting that a higher score, indicating "healthier" consumption, was associated with a lower HbA_{1c} compared with those with a lower HEI score or subscore.

As an example, compared with an otherwise identical participant with a total vegetable subscore of 0, representing no vegetable intake, a participant with the maximum score of 5, representing ≥1.1 cups of vegetables per 1,000 kcal a day, would have an estimated change in HbA_{1c} that was 0.5 HbA_{1c} percentage points less per year, or a full point lower (i.e., HbA_{1c} of 7.0 vs. 8.0%) over the 2-year study period.

CONCLUSIONS

In this sample of largely low-income Puerto Rican diabetic patients, food insecurity was associated with lower overall dietary quality. This pattern, in turn, was associated with poor longitudinal glycemic control, of a magnitude that is clinically significant. In exploratory analyses, lower consumption of total

Table 3—Associations between HEI score and longitudinal glycemic control

	Unadjusted		Fully adjusted**	
HEI	β coefficient* (95% CI)	*P* value	β coefficient* (95% CI)	*P* value
Total	**−0.014 (−0.022, −0.005)**	**0.003**	**−0.014 (−0.023, −0.005)**	**0.003**
Total fruit	−0.028 (−0.080, 0.025)	0.30	−0.028 (−0.083, 0.026)	0.30
Whole fruit	−0.017 (–0.068, 0.034)	0.51	−0.024 (−0.076, 0.029)	0.38
Total vegetables	**−0.101 (–0.184, −0.019)**	**0.02**	**−0.092 (−0.178, −0.006)**	**0.04**
Dark green and orange vegetables and legumes	**−0.057 (−0.111, −0.003**	**0.04**	**−0.057 (−0.113, −0.001)**	**0.048**
Total grains	−0.086 (–0.197, 0.024)	0.13	−0.083 (−0.197, 0.030)	0.15
Whole grains	−0.032 (−0.091, 0.028)	0.30	−0.034 (−0.100, 0.027)	0.28
Milk	−0.015 (−0.045, 0.016)	0.31	−0.017 (−0.048, 0.014)	0.30
Meat and beans	−0.028 (−0.134, 0.077)	0.60	−0.020 (−0.129, 0.089)	0.71
Oils	−0.036 (−0.090, 0.017)	0.18	−0.033 (−0.089, 0.022)	0.24
Saturated fats	−0.019 (−0.051, 0.013)	0.24	−0.020 (−0.053, 0.013)	0.24
Sodium	0.030 (−0.003, 0.064)	0.08	0.026 (−0.009, 0.060)	0.14
Calories from SoFAAS	**−0.035 (−0.056, −0.014)**	**0.001**	**−0.034 (−0.055, −0.013)**	**0.002**

Boldface indicates $P < 0.05$. *β coefficients represent change in HbA_{1c} per 1 point in HEI 2005 score or subscore, per year. A negative coefficient represents a decrease in HbA_{1c} over time. **Fully adjusted model represents adjustment for the following: age, sex, education, income-to-poverty ratio, BMI, glucose-lowering medications (metformin, sulfonylureas, thiazolidinediones, and insulin), physical activity, smoking, and alcohol use.

fruit, whole fruit, total vegetables, and dark green and orange vegetables and legumes was particularly associated with food insecurity, and for vegetable consumption, longitudinal glycemic control. Higher dietary quality was associated with greater improvement in HbA_{1c} over time in food-insecure, compared with food-secure, participants.

These findings are consistent with and extend those of prior reports. Food insecurity is common in diabetic patients (4–6), and although associations between diet and food insecurity have been studied in the general population, the dietary patterns of food-insecure diabetic patients have been studied in less detail (24). Although food insecurity is less common in Massachusetts than many other states, the reported rate of food insecurity in this sample was more than triple that of the state overall in the baseline period (26% in our sample vs. 8% in the state) (25). HbA_{1c} was higher in food-insecure patients, but this result only approached significance in this sample. This is likely due to lower power for this outcome, as our study was mainly powered to look at dietary patterns; a prior study that detected statistically significantly higher HbA_{1c} in food-insecure diabetic patients included four times as many food-insecure participants (4), although the point estimate of the difference in HbA_{1c} between the groups was similar. Additionally, the very high mean HbA_{1c} suggests that these participants are living in an environment with many factors pushing them toward hyperglycemia. In such an environment, food insecurity may be only one of many adverse circumstances. The significant interaction term between food insecurity and dietary quality with regard to glycemic control is also worth noting; dietary quality was more strongly associated with subsequent HbA_{1c} in food-insecure participants, compared with those who report food security. This observation suggests improving diet quality in food-insecure participants may be an important strategy for reducing disparities in diabetes outcomes. We found no significant differences in dietary pattern between those with "low food security" compared with those with "very low food security," implying that there may be a threshold association between food insecurity and dietary pattern in this population. This, in turn, may be relevant for programs aiming to improve food security and dietary quality in diabetic patients.

Overall, the dietary patterns of food-insecure diabetic patients we report are similar to those of the general population (7,9,10). Whereas prior cross-sectional studies have demonstrated that food insecurity is associated with poor diabetes control, our findings shed light on a potential mechanism (lower vegetable consumption) that is associated with greater improvement in HbA_{1c} over time. Because supplementation of plant-based foods is an emerging strategy in managing cardiovascular disease risk (26), as is community-based diabetes management programs with nutritional intervention (27), more detailed knowledge of dietary patterns in food-insecure diabetic patients may prove useful to help inform future interventions.

These findings have implications for both public health and clinical practice. Diabetes, especially very high glycemia, such as $HbA_{1c} > 9.0\%$ (75 mmol/mol), is known to be responsive to diet (28), and medical nutrition therapy is a key part of diabetes management. However, dietary advice must be tailored to patient circumstances, and thus knowledge of which foods are and are not accessible is important for clinicians. Additionally, these findings are important for community health and public policy discussions around food access. We found little difference between food-insecure and food-secure participants with diabetes in consumption of sugar-sweetened beverages or saturated fats, but significant differences in produce intake. Thus, particular efforts to reduce the point-of-purchase costs for fresh vegetables may be an important strategic target to improve diabetes outcomes in food-insecure patients specifically. Suggestions such as providing a produce "subsidy" in nutrition assistance programs, such as the Supplemental Nutrition Assistance Program (SNAP, formerly the Food Stamp Program), may be an import policy tool in reducing the burden of diabetes on poor health outcomes in vulnerable populations (29). As SoFAAS were associated with poorer diabetes control, and their consumption was similar for both food-secure and food-insecure patients, efforts to limit the purchase of, for example, sugar-sweetened beverages might be broadly useful, rather than only in the context of a nutrition assistance program.

This study has several limitations. First, the study is set in a Puerto Rican community in the Northeastern U.S. Although this is important given the high burden of diabetes in Hispanic communities and the relative underinclusion of Hispanic diabetic patients in many studies (1), it may also limit the generalizability of these findings. In particular, as Puerto Ricans are U.S. citizens, issues of access to nutrition assistance programs such as SNAP are likely less pronounced than in Hispanic communities with more documentation issues. This would be expected to increase risk of food insecurity and its possible effect on diabetes control for other communities (30). Second, although we adjusted for a robust set of potential confounders, residual confounding may exist for unmeasured factors. This may be especially true for some clinical factors such as medication dose and adherence, which were not available in our data set. Finally, food insecurity is a dynamic state, with many people having recurrent episodes of food insecurity followed by periods of food security (3,7). Because our study sample, overall, reports relatively low income, participants not experiencing food insecurity at baseline may still have experienced it prior to their follow-up visit. This potential misclassification may make the diabetes control of the nominal food-insecure and food-secure groups appear to be more similar than it otherwise would be. These limitations are balanced by several strengths. This study used a population-based sampling frame, which limits bias introduced by recruiting only from populations in contact with the health care system. This is especially important for vulnerable patients, who may have less access to health care. Similarly, defining diabetes using laboratory values obtained for all patients minimizes underascertainment of diabetes status in groups with less clinical contact. Also, the prospective, longitudinal design is a key strength, allowing us to assess baseline dietary quality and its association with subsequent changes in HbA_{1c} and thus evaluate time ordering of the exposure and outcome.

Diet quality may be particularly important for food-insecure diabetic patients. Therefore, the association between food insecurity and poor dietary quality, especially with regard to vegetable consumption, may be an important consideration for both clinicians and those working with nutrition policy. Future research should test whether interventions that materially support reductions in food insecurity and increases in vegetable consumption improve health in vulnerable diabetic patients.

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