Dietary glycemic index and load, measures of glucose metabolism, and body fat distribution in older adults[1–3]

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ABSTRACT

Background: Recent evidence suggests that the rate of carbohydrate digestion and absorption may influence the development of type 2 diabetes.

Objective: The aim of this study was to examine associations of dietary glycemic index and glycemic load with predictors of type 2 diabetes in older adults.

Design: This study evaluated cross-sectional relations of dietary glycemic index and glycemic load with measures of glucose metabolism and body fat distribution in participants of the Health, Aging and Body Composition Study, a prospective cohort study of adults aged 70–80 y (n = 2248).

Results: In men, dietary glycemic index was positively associated with 2-h glucose (P for trend = 0.04) and fasting insulin (P for trend = 0.004), inversely associated with thigh intramuscular fat (P for trend = 0.02), and not significantly associated with fasting glucose, glycated hemoglobin, or visceral abdominal fat. Dietary glycemic load was inversely associated in men with visceral abdominal fat (P for trend = 0.02) and not significantly associated with fasting glucose, 2-h glucose, glycated hemoglobin, fasting insulin, or thigh intramuscular fat. In women, although dietary glycemic index and load were not significantly related to any measures of glucose metabolism or body fat distribution, the association between dietary glycemic index and 2-h glucose was nearly significant (P for trend = 0.06).

Conclusion: The findings of this cross-sectional study indicate an association between dietary glycemic index and selected predictors of type 2 diabetes in older adults, particularly in men. *Am J Clin Nutr* 2005;82:547–52.

KEY WORDS Glycemic index, glycemic load, glucose metabolism, insulin resistance, body composition, older adults

INTRODUCTION

In the past 2 decades, the prevalence of type 2 diabetes in the United States has more than doubled (1). Although both health behaviors and genetic factors have been associated with risk of type 2 diabetes, a condition characterized by disordered carbohydrate metabolism, the role of dietary carbohydrate is debated. Most large-scale epidemiologic studies have found little relation between intake of total carbohydrate and development of type 2 diabetes (2). To determine whether the rate of carbohydrate digestion and absorption influences health, studies have examined the glycemic index (GI) and glycemic load (GL), which classify carbohydrate-containing foods according to their effects on postprandial blood glucose concentrations (3, 4). Whether dietary GI or GL is implicated in the development of type 2 diabetes remains unclear.

The GI is included in dietary recommendations for prevention and management of diabetes in Europe as well as in Australia and Canada, but its use is not fully endorsed by the American Diabetes Association (5, 6). As suggested by Foster-Powell et al (5), methodologic differences in different laboratories can produce discrepant GI values for the same foods, which casts doubt on published GI estimates. It is also debated whether GI values of individual foods can be pooled to accurately predict the glycemic response to mixed meals (7, 8).

A report of the Institute of Medicine, *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids*, stated "a need for more research to elucidate the metabolic and long-term health differences resulting from the ingestion of high compared with low GI carbohydrates using larger, diverse samples" (8). Also, although ≈40% of persons with type 2 diabetes are ≥65 y, few studies have examined relations of dietary GI or GL with predictors of type 2 diabetes in this age group. The objective of the current study was thus to examine the associations of dietary GI and GL with predictors of type 2 diabetes, including measures of glucose metabolism and body fat distribution, in a relatively large, biracial cohort of older adults.

SUBJECTS AND METHODS

Subjects

The Health, Aging and Body Composition (Health ABC) Study is a prospective cohort study to investigate relations

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among health conditions, body composition, behavioral and social factors, and physical function in older adults. The 3075 participants aged 70–79 y were recruited from a random sample of white Medicare beneficiaries and all age-eligible black community residents in designated ZIP code areas of Pittsburgh, PA, and Memphis, TN. Individuals were eligible if they reported no life-threatening cancers; had no difficulty walking one-quarter mile, climbing 10 steps, performing basic activities of daily living, or getting around without assistive devices; were not participating in any research studies that involved medications or modification of eating or exercise habits; and planned to remain in the area for at least 3 y. Protocols were approved by institutional review boards at both study sites, and participants provided written, informed consent.

An interview on demographic and socioeconomic factors and health behaviors and health status plus a clinical examination of body composition, biochemical variables, weight-related health conditions, and physical function were administered between 1997 and 1998, with annual follow-up assessments. Results from baseline and year 2 of the Health ABC study were used in the current analyses. Participants were excluded from these analyses if they reported following a special diabetic diet ($n = 45$), using medication for diabetes ($n = 363$), or had incomplete dietary data ($n = 13$) or sociodemographic and lifestyle information ($n = 47$). In each analysis, those with missing values for the outcome variable were also excluded, and final sample sizes ranged from 2152 for the analysis of glucose tolerance to 2248 for that of fasting glucose.

Assessment of diet and calculation of dietary glycemic index and load

Food intake was measured in the second year of the Health ABC study with a 108-item food-frequency questionnaire (FFQ). This FFQ was designed specifically for the Health ABC study by Block Dietary Data Systems (Berkeley, CA), based on reported intakes of non-Hispanic white and black residents of the Northeast and South aged ≥65 y in the third National Health and Nutrition Examination Survey. The FFQ was administered by a trained dietary interviewer, and intakes of nutrients and food groups were estimated by Block Dietary Data Systems.

The GI of a food is defined as the 2-h incremental area under the blood glucose curve after consumption of a food portion that contains a specific amount, usually 50 g, of available carbohydrate, divided by the corresponding area after consumption of a portion of a reference food, usually glucose or white bread, which contains the same amount of available carbohydrate, and multiplied by 100 to be expressed as a percentage. GI values for foods in FFQ of the Health ABC study were compiled from the literature by the Clinical Nutrition Research Center of the University of North Carolina, and modified if necessary to better match FFQ foods (5). A computer program was written with the use of SAS (SAS Institute Inc, Cary, NC) to calculate the dietary GI and GL for each participant. The program first determined the amount of available carbohydrate in one serving of each food by subtracting the amount of fiber from the amount of total carbohydrate per serving. To obtain the GL of a serving of the food, the amount of available carbohydrate per serving was multiplied by the GI value of the food and divided by 100. To determine the dietary GL of each subject, each food's GL was multiplied by the daily frequency of consumption of the food, and these products were summed over all foods. The dietary GI of each subject was computed by dividing dietary GL by daily intake of total available carbohydrate and multiplying by 100. These methods of calculating dietary GI and GL are endorsed by a joint report of the Food and Agriculture Organization (FAO) and the World Health Organization (WHO), and by the *International Table of Glycemic Index and Glycemic Load Values: 2002* (5, 9).

Measures of glucose metabolism

Fasting glucose was assessed at baseline and year 2, and glycated hemoglobin and fasting insulin were assessed at baseline of the Health ABC study, from blood drawn through venipuncture after an overnight fast and stored at −70 °C. Plasma glucose was measured by an automated glucose oxidase reaction (YSI 2300 Glucose Analyzer; Yellow Springs Instruments, Yellow Springs, OH), glycated hemoglobin by HPLC (Biorad Diamat, Richmond, CA), and serum insulin with a commercially available radioimmunoassay kit (Pharmacia, Uppsala, Sweden). To evaluate glucose tolerance, an oral glucose tolerance test was administered at baseline to participants without diagnosed type 2 diabetes. After blood was drawn for glucose and insulin measurements, participants ingested 75 g glucose in solution (glucola), and another blood sample was drawn after 2 h. Biological specimens were processed according to standardized protocols by the Laboratory of Clinical Biochemistry at the University of Vermont (10).

Measures of body composition

At baseline of the Health ABC study, participants underwent axial computed tomography scanning of the abdomen and thigh. Visceral abdominal fat and intramuscular fat from the right and left thighs were quantified from scans performed on a General Electric 9800 Advantage (Milwaukee, WI) in Pittsburgh and a Siemens Somatom (Iselin, NJ) and Picker PQ2000S (Cleveland, OH) in Memphis. All data from computed tomography scans were analyzed at the University of Colorado Health Sciences Center according to a standardized protocol (11). Total fat mass was assessed at baseline and year 2 by dual-energy X-ray absorptiometry (Hologic QDR 4500A, software version 8.21; Hologic, Waltham, MA). Weight in kilograms was measured annually with a standard balance beam scale, and height in meters was measured twice at baseline with a Harpenden stadiometer (Holtain Ltd, Crosswell, United Kingdom). After averaging the 2 height measurements, body mass index (BMI; in kg/m^2) was calculated.

Sociodemographic and lifestyle variables

Sociodemographic variables, including age, sex, self-identified racial group, and level of education, and lifestyle variables, including smoking status, alcohol consumption, and level of physical activity, were assessed at baseline of the Health ABC study. Lifetime pack-years of cigarette smoking were calculated by multiplying cigarette packs smoked per day by the number of years of smoking. Level of physical activity was ascertained by a standardized questionnaire specifically designed for the Health ABC study. This questionnaire was derived from the Leisure Time Physical Activity Questionnaire and included additional activities commonly performed by older adults (12). The frequency, duration, and intensity level of specific activities were determined, and approximate metabolic equivalent unit values

were assigned to each activity category to estimate weekly energy expenditure in kcal · kg^{-1} · wk^{-1}. Total physical activity was calculated as weekly energy expenditure multiplied by body weight.

Statistical analysis

Unpaired Student's *t* test and chi-square test were used to compare characteristics of men and women. Multiple regression models were constructed by sex to evaluate cross-sectional associations of dietary GI and GL with visceral abdominal fat, intramuscular fat, fasting glucose, glucose tolerance, glycated hemoglobin, and fasting insulin concentrations. Because fasting glucose, 2-h glucose, and fasting insulin concentrations had positively skewed distributions, natural logarithm transformations of these variables were used in the analyses, and inverse transformations were performed to obtain geometric means. Dietary GI and GL were adjusted for total calorie intake by using the residuals method of Willett et al (13) and categorized into quintiles. Covariates included age, race, BMI, level of physical activity, level of education, alcohol consumption, smoking status, and intake of total fiber or cereal fiber. To assess trends across quintile categories, participants were assigned the median quintile value, and this value was modeled as a continuous variable in linear regression models. Means of quintiles 2 through 5 were compared with means of quintile 1 with Dunnett's test. Statistical significance was set at $P \leq 0.05$, and analyses were performed with the use of SAS (version 8.1; SAS Institute Inc).

RESULTS

Characteristics of men and women in the overall study population are shown in **Table 1** and in **Table 2** according to quintile of energy-adjusted dietary GL. Men in the higher quintiles of dietary GL had a higher mean age and were less likely to consume alcohol. Women in the higher quintiles of dietary GL included fewer white participants and consumers of alcohol and on average had fewer pack-years of smoking. Characteristics of men and women by quintile of energy-adjusted GI followed similar patterns (results not shown). Men and women in the higher quintiles of dietary GI were less likely to consume alcohol, and men were less physically active on average.

The least square means of glucose-related measures and body fat measures according to energy-adjusted quintiles of dietary GI, with additional adjustments for age, race, education, physical activity, BMI, alcohol consumption, and smoking status, are shown in **Table 3**. In men, dietary GI was positively associated with 2-h glucose concentrations and fasting insulin concentrations and inversely associated with thigh intramuscular fat. Dietary GI was not significantly associated with fasting glucose, glycated hemoglobin, or visceral abdominal fat. In women, dietary GI was not significantly associated with any glucose-related or body fat measures, but the association between dietary GI and 2-h glucose approached significance. In all models, additional control for intake of total fiber or cereal fiber did not appreciably alter results.

Least square means of glucose-related measures and body fat measures according to energy-adjusted quintiles of dietary GL, with additional adjustment for age, race, education, physical activity, BMI, alcohol consumption, and smoking status, are presented in **Table 4**. In men, dietary GL was inversely associated with visceral abdominal fat and was not significantly associated with fasting glucose, 2-h glucose, glycated hemoglobin, fasting insulin, or thigh intramuscular fat. In women, dietary GL was not significantly associated with any measures of glucose metabolism or body fat distribution. As before, adjustment for intake of total fiber or cereal fiber did not markedly affect results.

TABLE 1
Characteristics of the study population

	Men (n = 1079)	Women (n = 1169)
Age (y)[1]	75.3 ± 2.9[2]	75.0 ± 2.9
Race (% white)[3]	68	60[4]
Education (% completed high school)[3]	76	81
Total energy intake (kcal)[1]	2082 ± 844	1710 ± 660[5]
Total carbohydrate intake (g)[1]	273 ± 110	228 ± 90[5]
Total fiber intake (g)[1]	18.5 ± 8.3	16.9 ± 7.4[5]
Cereal fiber intake (g)[1]	9.4 ± 4.9	7.9 ± 4.1[5]
Smoking (lifetime pack-years)[3]	25.7 ± 30.7	12.0 ± 22.4[5]
Alcohol (% drinkers)[3]	61	47[4]
Physical activity (kcal/wk)[3]	1476 ± 2237	762 ± 1280[5]
BMI (kg/m^2)[1]	26.7 ± 3.9	27.0 ± 5.4
Total body fat (%)[1]	28.1 ± 5.1	39.2 ± 6.0[5]
Visceral abdominal fat (cm^2)[3]	151.7 ± 68.5	124.4 ± 58.0[5]
Right thigh intramuscular fat (cm^2)[3]	9.6 ± 5.8	10.2 ± 6.1[5]
Fasting glucose (mg/dL)[1]	97.4 ± 15.6	92.5 ± 12.8[5]
2-h Glucose (mg/dL)[3]	128.6 ± 48.7	131.2 ± 45.2[5]
Hemoglobin A_{1c} (%)[3]	6.1 ± 0.6	6.0 ± 0.6
Fasting insulin (μU/mL)[3]	8.1 ± 5.4	8.1 ± 5.6
Unadjusted dietary glycemic load (glucose scale)[1]	145.2 ± 61.3	118.3 ± 49.6[5]
Unadjusted dietary glycemic index (glucose scale)[1]	56.8 ± 4.2	55.8 ± 4.0[5]

[1] Values from year 2 of the Health, Aging and Body Composition (Health ABC) Study.
[2] $\bar{x}$ ± SD (all such values).
[3] Values from baseline of the Health ABC Study.
[4,5] Significantly different from men: [4] $P \leq 0.05$ (chi-square test), [5] $P \leq 0.05$ (unpaired Student's *t* test).

DISCUSSION

In this cohort of well-functioning older adults, dietary GI was associated with several glucose-related measures. In men, dietary GI was positively related to 2-h glucose and fasting insulin concentrations, and, in women, the association between dietary GI and 2-h glucose approached significance. Although dietary GI and GL may have different physiologic effects in men and women, this is not supported by results of other cohort studies (2, 4, 14, 15).

Accumulation of fat in the visceral abdominal and skeletal muscle areas has been linked to increased risk of type 2 diabetes in the Health ABC cohort, and the current study did not find a positive association between dietary GI or GL and either measure of fat distribution (16). On the contrary, inverse relations were seen in men between dietary GI and thigh intramuscular fat, as well as between dietary GL and visceral abdominal fat. These findings differ from results of the cross-sectional EURODIAB study of persons aged 14–61 y, which positively associated

TABLE 2
Characteristics of the men and women by quintile of energy-adjusted dietary glycemic load

	Quintile of dietary glycemic load					
	1	2	3	4	5	P^1
Men (n = 1079)						
Dietary glycemic load[2]	107.4 ± 18.5[3]	132.7 ± 3.8	143.9 ± 3.0	156.8 ± 4.7	185.3 ± 19.2	—
n	216	216	216	216	215	—
Age (y)[2]	74.8 ± 2.8	75.1 ± 2.9	75.1 ± 2.8	75.8 ± 2.9	75.6 ± 2.9	0.0002
Race (% white)[4]	69	70	71	66	65	0.26
Education (% completed high school)[4]	78	77	75	74	73	0.20
Total energy intake (kcal)[2]	2347 ± 997	1860 ± 749	1830 ± 756	2025 ± 702	2349 ± 832	0.25
Smoking (lifetime pack-years)[4]	30.7 ± 32.1	24.2 ± 28.4	22.5 ± 27.6	27.1 ± 32.5	24.0 ± 32.0	0.09
Alcohol (% drinkers)[4]	81	65	63	51	47	< 0.0001
Physical activity (kcal/wk)[4]	1918 ± 439	1221 ± 1475	1374 ± 1816	1514 ± 2091	1351 ± 1775	0.05
Total body fat (%)[2]	28.2 ± 5.1	28.2 ± 5.1	28.1 ± 5.1	28.2 ± 5.6	27.6 ± 4.7	0.27
BMI (kg/m^2)[2]	26.7 ± 4.2	26.8 ± 4.0	26.8 ± 3.4	26.6 ± 4.2	26.7 ± 3.4	0.74
Women (n = 1169)						
Dietary glycemic load[2]	88.5 ± 15.1	108.7 ± 3.1	118.2 ± 2.8	128.0 ± 3.3	148.3 ± 14.3	—
n	234	234	234	234	233	—
Age (y)[2]	74.8 ± 2.9	75.1 ± 2.9	75.0 ± 2.8	75.2 ± 2.9	75.2 ± 2.9	0.18
Race (% white)[4]	64	65	64	58	52	0.002
Education (% completed high school)[4]	82	79	85	84	75	0.31
Total energy intake (kcal)[2]	1961 ± 710	1540 ± 576	1506 ± 584	1663 ± 569	1880 ± 723	0.63
Smoking (lifetime pack-years)[4]	17.8 ± 27.7	13.4 ± 24.8	11.9 ± 20.8	9.3 ± 19.3	7.6 ± 16.3	< 0.0001
Alcohol (% drinkers)[4]	59	52	44	44	34	< 0.0001
Physical activity (kcal/wk)[4]	778 ± 1135	850 ± 1492	708 ± 917	593 ± 719	882 ± 1817	0.91
Total body fat (%)[2]	39.3 ± 6.0	38.9 ± 6.1	40.3 ± 5.8	38.6 ± 5.6	39.0 ± 6.2	0.58
BMI (kg/m^2)[2]	27.4 ± 5.4	26.7 ± 5.4	27.8 ± 5.6	26.2 ± 4.9	27.1 ± 5.7	0.30

[1] For continuous variables, tests for linear trend used the median value in each quintile as a continuous variable in linear regression; a Mantel-Haenszel chi-square test was used for categorical variables.
[2] Values from year 2 of the Health, Aging and Body Composition (Health ABC) Study.
[3] $\bar{x}$ ± SD (all such values).
[4] Values from baseline of the Health ABC Study.

dietary GI to waist-hip ratio and waist circumference in men (17). Unlike the current study population, however, EURODIAB participants spanned a wide age range and had type 1 diabetes, and metabolic alterations could affect relations of dietary GI and GL with body fat distribution (17).

The associations in this cohort between dietary GI and specific measures of glucose metabolism partly confirm findings of the Framingham Offspring Cohort Study, in which both dietary GI and GL were positively related to insulin resistance in cross-sectional analyses (15). In the Zutphen Elderly Study, however, no cross-sectional relation was seen between dietary GI and fasting insulin concentrations or other metabolic risk factors among men aged 64–84 y (18). In longitudinal analyses, the Atherosclerosis Risk in Communities and the Iowa Women's Health studies showed no association between dietary GI and incident type 2 diabetes (14, 19). Conversely, in the Nurses' Health Study I, subjects in the highest compared with the lowest quintile of dietary GI or GL had an ≈40–50% greater risk of developing type 2 diabetes after adjustment for intake of cereal fiber, and similar positive relations were seen between dietary GI and type 2 diabetes risk in the Health Professionals Follow-up Study, the Nurses' Health Study II, and the Melbourne Collaborative Cohort Study (2, 4, 20, 21). It was suggested that hyperglycemic and hyperinsulinemic effects of a high dietary GI or GL might impair pancreatic β-cell function, particularly in insulin-resistant individuals, and thereby lead to type 2 diabetes (2, 4, 20, 22).

Comparing study findings may not be valid, however, when methods of calculating dietary GI and GL differ. An individual's dietary GL was defined in initial cohort studies as the product of the total carbohydrate content per serving of each food, the average daily number of servings of the food consumed by the individual, and the food's GI, divided by 100 and summed across all foods (2, 4). Dietary GI was obtained by dividing dietary GL by daily total carbohydrate intake and multiplying by 100. These formulas contain total rather than available carbohydrate, which is used in the joint FAO/WHO report, the *International Table of Glycemic Index and Glycemic Load Values: 2002*, several experimental studies, and current analyses (5, 9, 23–26). According to the method of the Association of Official Analytic Chemists, available carbohydrate is calculated as total carbohydrate minus dietary fiber, because other unabsorbed carbohydrates such as resistant starch are difficult to quantify (5, 23). Use of total instead of available carbohydrate can considerably alter dietary GL values, because some foods have a high fiber content, and can also change dietary GI values, because foods vary in their ratios of total to available carbohydrate.

The choice of reference food also influences dietary GI and GL values and may need to be considered when comparing results of different studies. Glucose-based dietary GI or GL is multiplied by 1.43 to obtain white bread-based dietary GI or GL. The current study used glucose-based GI values, consistent with the *International Table of Glycemic Index and Glycemic Load Values: 2002*,

TABLE 3
Body fat and glucose-related measures according to energy-adjusted quintiles of dietary glycemic index

	Quintile of dietary glycemic index					
	1	2	3	4	5	*P* for trend[1]
Men (n = 1079)						
Dietary glycemic index quintile median[2]	51.7	54.8	56.8	59.0	61.9	—
Fasting glucose (mg/dL)[2]	96.9 ± 0.9[3]	96.3 ± 0.9	94.7 ± 0.9	97.3 ± 0.9	96.5 ± 0.9	0.95
2-h Glucose (mg/dL)[4]	118.4 ± 2.9	120.0 ± 2.9	116.2 ± 2.8	123.0 ± 2.9	126.9 ± 3.2	0.04
Hemoglobin A_{1c} (%)[4]	6.0 ± 0.0	6.1 ± 0.0	6.0 ± 0.0	6.1 ± 0.0	6.1 ± 0.0	0.50
Fasting insulin (μU/mL)[4]	6.1 ± 0.2	6.8 ± 0.2	7.0 ± 0.2[5]	6.8 ± 0.2	7.2 ± 0.3[6]	0.004
Visceral abdominal fat (cm^2)[4]	153.3 ± 3.6	155.4 ± 3.7	150.9 ± 3.6	149.1 ± 3.6	149.6 ± 3.7	0.28
Right thigh intramuscular fat (cm^2)[4]	9.9 ± 0.3	9.7 ± 0.3	10.1 ± 0.3	9.3 ± 0.3	8.9 ± 0.3	0.02
Women (n = 1169)						
Dietary glycemic index quintile median[2]	50.9	53.9	55.7	57.8	60.8	—
Fasting glucose (mg/dL)[2]	91.9 ± 0.7	92.1 ± 0.7	91.3 ± 0.7	92.2 ± 0.7	91.4 ± 0.7	0.68
2-h Glucose (mg/dL)[4]	119.1 ± 2.6	124.5 ± 2.7	126.0 ± 2.7	125.9 ± 2.7	126.3 ± 2.7	0.06
Hemoglobin A_{1c} (%)[4]	6.0 ± 0.0	6.0 ± 0.0	6.0 ± 0.0	6.0 ± 0.0	6.0 ± 0.0	0.93
Fasting insulin (μU/mL)[4]	6.9 ± 0.2	7.1 ± 0.2	6.8 ± 0.2	7.0 ± 0.2	6.9 ± 0.2	0.93
Visceral abdominal fat (cm^2)[4]	119.3 ± 3.1	124.4 ± 3.1	125.6 ± 3.0	128.2 ± 3.1	124.3 ± 3.1	0.17
Right thigh intramuscular fat (cm^2)[4]	10.3 ± 0.3	10.0 ± 0.3	9.6 ± 0.3	10.7 ± 0.3	10.1 ± 0.3	0.92

[1] Tests for linear trend used the median value in each quintile as a continuous variable in the linear regression.
[2] Values from year 2 of the Health, Aging and Body Composition (Health ABC) Study.
[3] All such values are least-squares $\bar{x}$ ± SE (geometric $\bar{x}$ of fasting glucose, 2-h glucose, and fasting insulin concentrations), adjusted for age, race, education, physical activity, BMI, alcohol consumption, and smoking status.
[4] Values from baseline of the Health ABC Study.
[5,6] Significantly different from quintile 1 (Dunnett's test): [5] $P = 0.03$, [6] $P = 0.007$.

whereas previous cohort studies generally used white bread-based GI values (2, 4, 14, 15, 18, 19). Differences in dietary GI and GL formulas and in the choice of reference food may partly explain lower dietary GI and GL values found in this study and in the Melbourne Collaborative Cohort Study compared with most other studies (2, 4, 14, 15, 18–21). The relative homogeneity of this study population with respect to age and functional status may have contributed also to narrower dietary GI and GL ranges compared with most other studies and may have attenuated associations between dietary GI and GL and health outcomes.

Because the sample size in this study did not allow for simultaneous analysis by both sex and race, these subgroup analyses

TABLE 4
Body fat and glucose-related measures according to energy-adjusted quintiles of dietary glycemic load[1]

	Quintile of dietary glycemic load					
	1	2	3	4	5	*P* for trend[2]
Men (n = 1079)						
Dietary glycemic load quintile median[3]	113.7	132.9	143.8	156.5	179.7	—
Fasting glucose (mg/dL)[3]	96.7 ± 0.9[4]	95.8 ± 0.9	96.3 ± 0.9	95.5 ± 0.9	97.4 ± 0.9	0.55
2-h Glucose (mg/dL)[5]	116.1 ± 2.9	120.2 ± 2.9	123.2 ± 3.0	120.3 ± 2.9	124.4 ± 3.1	0.08
Hemoglobin A_{1c} (%)[5]	6.1 ± 0.0	6.1 ± 0.0	6.1 ± 0.0	6.0 ± 0.0	6.1 ± 0.0	0.60
Fasting insulin (μU/mL)[5]	6.7 ± 0.2	6.8 ± 0.2	6.9 ± 0.2	6.8 ± 0.2	6.9 ± 0.3	0.55
Visceral abdominal fat (cm^2)[5]	157.2 ± 3.8	152.8 ± 3.6	152.9 ± 3.6	151.0 ± 3.7	144.5 ± 3.6	0.02
Right thigh intramuscular fat (cm^2)[5]	9.9 ± 0.3	9.4 ± 0.3	9.7 ± 0.3	9.7 ± 0.3	9.1 ± 0.3	0.16
Women (n = 1169)						
Dietary glycemic load quintile median[3]	92.7	109.1	118.3	127.6	144.8	—
Fasting glucose (mg/dL)[3]	92.2 ± 0.7	91.9 ± 0.7	91.5 ± 0.7	91.8 ± 0.7	91.4 ± 0.7	0.45
2-h Glucose (mg/dL)[5]	122.4 ± 2.7	123.0 ± 2.7	124.2 ± 2.7	126.7 ± 2.7	125.5 ± 2.7	0.30
Hemoglobin A_{1c} (%)[5]	6.0 ± 0.0	6.0 ± 0.0	6.1 ± 0.0	6.0 ± 0.0	5.9 ± 0.0	0.25
Fasting insulin (μU/mL)[5]	7.2 ± 0.2	6.9 ± 0.2	7.0 ± 0.2	6.8 ± 0.2	6.8 ± 0.2	0.26
Visceral abdominal fat (cm^2)[5]	127.7 ± 3.1	119.6 ± 3.1	124.1 ± 3.1	129.4 ± 3.1	120.9 ± 3.1	0.47
Right thigh intramuscular fat (cm^2)[5]	10.4 ± 0.3	9.7 ± 0.3	10.2 ± 0.3	10.0 ± 0.3	10.5 ± 0.3	0.71

[1] No significant differences were found between quintiles 1 and 2, 3, 4, or 5 for any of the variables (Dunnett's test).
[2] Tests for linear trend used the median value in each quintile as a continuous variable in linear regression.
[3] Values from year 2 of the Health, Aging and Body Composition (Health ABC) Study.
[4] All such values are least-squares $\bar{x}$ ± SE (geometric $\bar{x}$ of fasting glucose, 2-h glucose, and fasting insulin concentrations), adjusted for age, race, education, physical activity, BMI, alcohol consumption, and smoking status.
[5] Values from baseline of the Health ABC Study.

were performed separately. Analyses by race showed that in white participants, dietary GI was positively related to 2-h glucose and fasting insulin concentrations, as found in men in analyses by sex, and dietary GL was positively associated with 2-h glucose concentration. In black participants, no significant associations were seen between dietary GI or GL and any measures of glucose metabolism or fat distribution, as found in women in analyses by sex. The positive relations found in men may thus have been driven by results for white men.

This study has several limitations that may have influenced results. Jenkins et al (27) proposed that the lack of a relation between dietary GI or GL and adverse health outcomes in the Iowa Women's Health and Zutphen Elderly Studies of older adults may have been due to baseline exclusion of individuals with diabetes and other chronic diseases and thus of a large proportion of vulnerable subjects. Selection bias could have attenuated relations found in this study, whose population consisted of well-functioning older adults without type 2 diabetes. Furthermore, although FFQs are considered informative for ranking individuals by intake in large samples, the FFQ in this study was not specifically designed to derive dietary GI or GL values and thus may not have captured the total glycemic effect of the diet. In addition, whereas most outcome variables and several control variables in this study were measured at baseline, diet was assessed at year 2, and this time discrepancy could have influenced results if participants substantially altered their intake between baseline and year 2. Finally, it is possible that these analyses did not include certain relevant confounders, because glucose metabolism and body fat distribution are influenced by a range of environmental and genetic factors. Any of these limitations could have introduced measurement error, resulted in a loss of statistical power, and diminished any actual associations. Strengths of this study include its large sample size considering the breadth and detail of biological measurements, unique study population of septuagenarians, and high percentage of African Americans.

In conclusion, this study showed dietary GI to be associated with specific measures of glucose metabolism in older adults, particularly in men. In the future, uniformity in methods of determining dietary GI and GL can allow more valid comparisons of results across studies and thus a better evaluation of whether dietary GI and GL are related to predictors of type 2 diabetes and other health outcomes. More longitudinal studies are needed to determine whether such relations may be causal.

NRS, ALA, and TBH were responsible for the study concept and the research design. ALA and NRS drafted the article. SBK was responsible for manuscript editing, advice, and consultation. AMK, PK-B, NDR, FAT, AVS, and JSL critically revised the article for important intellectual content. None of the authors had a conflict of interest.

REFERENCES

1. US Department of Health and Human Services. Internet: http://www.cdc.gov/diabetes/statistics/prev/national/figpersons.htm (accessed 27 May 2004).
2. Salmeron J, Ascherio A, Rimm EB, et al. Dietary fiber, glycemic load, and risk of NIDDM in men. Diabetes Care 1997;20:545–50.
3. Jenkins DJ, Wolever TM, Taylor RH, et al. Glycemic index of foods: a physiological basis for carbohydrate exchange. Am J Clin Nutr. 1981; 34:362–6.
4. Salmeron J, Manson JE, Stampfer MJ, Colditz GA, Wing AL, Willett WC. Dietary fiber, glycemic load, and risk of non-insulin-dependent diabetes mellitus in women. JAMA. 1997;277:472–7.
5. Foster-Powell K, Holt SH, Brand-Miller JC. International table of glycemic index and glycemic load values: 2002. Am J Clin Nutr. 2002;76:5–56.
6. Sheard NF, Clark NG, Brand-Miller JC, et al. Dietary carbohydrate (amount and type) in the prevention and management of diabetes: a statement by the American Diabetes Association. Diabetes Care 2004; 27:2266–71.
7. Flint A, Moller BK, Raben A, et al. The use of glycaemic index tables to predict glycaemic index of composite breakfast meals. Br J Nutr 2004; 91:979–89.
8. Institute of Medicine. Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids. Washington, DC: National Academy Press, 2002:248.
9. FAO/WHO Expert Consultation. Carbohydrates in human nutrition: report of a joint FAO/WHO Expert Consultation, Rome, 14-18 April 1997. Rome, Italy: Food and Agriculture Organization, 1998. (FAO Food and Nutrition paper 66.)
10. Health, Aging and Body Composition Study Operations Manual. Internet: http://www.keeptrack.ucsf.edu/ (accessed 14 January 2004).
11. Hill JO, Sidney S, Lewis CE, Tolan K, Scherzinger AL, Stamm ER. Racial differences in amounts of visceral adipose tissue in young adults: the CARDIA (Coronary Artery Risk Development in Young Adults) study. Am J Clin Nutr. 1999;69:381–7.
12. Taylor HL, Jacobs DR Jr, Schucker B, Knudsen J, Leon AS, Debacker G. A questionnaire for the assessment of leisure time physical activities. J Chronic Dis 1978;31:741–55.
13. Willett WC. Nutritional epidemiology. 2nd ed. New York, NY: Oxford University Press, 1998.
14. Stevens J, Ahn K, Juhaeri, Houston D, Steffan L, Couper D. Dietary fiber intake and glycemic index and incidence of diabetes in African-American and white adults: the ARIC study. Diabetes Care 2002;25:1715–21.
15. McKeown NM, Meigs JB, Liu S, Saltzman E, Wilson PW, Jacques PF. Carbohydrate nutrition, insulin resistance, and the prevalence of the metabolic syndrome in the Framingham Offspring Cohort. Diabetes Care 2004;27:538–46.
16. Goodpaster BH, Krishnaswami S, Resnick H, et al. Association between regional adipose tissue distribution and both type 2 diabetes and impaired glucose tolerance in elderly men and women. Diabetes Care 2003;26:372–9.
17. Toeller M, Buyken AE, Heitkamp G, Cathelineau G, Ferriss B, Michel G; EURODIAB IDDM Complications Study Group. Nutrient intakes as predictors of body weight in European people with type 1 diabetes. Int J Obes Relat Metab Disord. 2001;25:1815–22.
18. van Dam RM, Visscher AW, Feskens EJ, Verhoef P, Kromhout D. Dietary glycemic index in relation to metabolic risk factors and incidence of coronary heart disease: the Zutphen Elderly Study. Eur J Clin Nutr 2000;54:726–31.
19. Meyer KA, Kushi LH, Jacobs DR Jr, Slavin J, Sellers TA, Folsom AR. Carbohydrates, dietary fiber, and incident type 2 diabetes in older women. Am J Clin Nutr 2000;71:921–30.
20. Schulze MB, Liu S, Rimm EB, Manson JE, Willett WC, Hu FB. Glycemic index, glycemic load, and dietary fiber intake and incidence of type 2 diabetes in younger and middle-aged women. Am J Clin Nutr 2004;80:348–56.
21. Hodge AM, English DR, O'Dea K, Giles GG. Glycemic index and dietary fiber and the risk of type 2 diabetes. Diabetes Care 2004;27:2701–6.
22. Brand-Miller JC. Glycemic load and chronic disease. Nutr Rev 2003; 61:S49–55.
23. Nantel G. Glycemic carbohydrate: an international perspective. Nutr Rev 2003;61:S34–9.
24. Ludwig DS. Dietary glycemic index and the regulation of body weight. Lipids 2003;38:117–21.
25. Brand-Miller JC, Thomas M, Swan V, Ahmad ZI, Petocz P, Colagiuri S. Physiological validation of the concept of glycemic load in lean young adults. J Nutr 2003;133:2728–32.
26. Wolever TM, Mehling C. Long-term effect of varying the source or amount of dietary carbohydrate on postprandial plasma glucose, insulin, triacylglycerol, and free fatty acid concentrations in subjects with impaired glucose tolerance. Am J Clin Nutr 2003;77:612–21.
27. Jenkins DJ, Kendall CW, Augustin LS, et al. Glycemic index: overview of implications in health and disease. Am J Clin Nutr 2002;76(suppl): 266–73S.