Glycemic load, glycemic index, and body mass index in Spanish adults[1–5]

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ABSTRACT

Background: Studies on obesity and glycemic index (GI) or glycemic load (GL) have had inconsistent results, perhaps in part because of underreporting or to heterogeneous dietary patterns across food cultures.

Objectives: We examined associations between body mass index (BMI) and GI or GL in a Mediterranean population, accounting for underreporting. We also constructed dietary factors related to GI and GL to better understand food patterns related to these measures.

Design: Cross-sectional data on 8195 Spanish adults aged 35–74 y were analyzed. A validated food-frequency questionnaire was used to estimate GI and GL, with glucose as the reference value. Reduced-rank regression was used to construct dietary patterns that explained variation in GI and GL. Multivariate linear regression was used to estimate associations between BMI and GI, GL, and their respective diet factors with and without adjusting for energy, which may lie on the causal pathway between glycemic quality and obesity. Effects of excluding underreporters (ratio of energy intake:basal metabolic rate < 1.20) were examined.

Results: Food patterns underlying high GI differed substantially from those of high GL, with fruits, vegetables, and legumes related positively to GL but negatively to GI. After excluding underreporters, GL was negatively associated with BMI, adjusting for energy. GI was not associated with BMI in any model.

Conclusions: After adjusting for energy, GL was associated with reduced BMI in this Mediterranean population. Underreporting did not explain this inverse relation, which was observed among subjects with plausible intakes. *Am J Clin Nutr* 2009;89:316–22.

INTRODUCTION

It is hypothesized that habitual consumption of carbohydrate-rich foods, which promote a high glycemic (blood glucose) response, may increase the risk of obesity (1–3). Few studies, however, have explored the relation between obesity and glycemic index (GI) or glycemic load (GL) in the usual diet, and results so far have been inconsistent. Cross-sectional studies on GI in relation to body mass index (BMI; in kg/m^2) or other measures of obesity have reported positive (4–6), null (7), and negative associations (8, 9). Similarly for GL, which takes into account the amount and the quality of carbohydrate ($GL = GI \times$ amount of available carbohydrate), studies have reported a mixture of positive (5, 6), null (4, 7), and negative (8, 9) associations with obesity. A longitudinal study also reported largely null associations between 6-y weight gain and dietary GI and GL, with the exception of a small positive association in sedentary women (10).

Several factors have been suggested to explain these inconsistent results. One study suggests that underreporting of intakes may play a role: strong positive associations between BMI and dietary GI and GL were observed after excluding underreporters or adjusting for energy intakes (5). Although they do not report accounting for underreporting, earlier studies also adjusted for energy (4, 6–11), and one study reported that a positive association between GL and BMI was completely attenuated, rather than strengthened, after this adjustment (7). Moreover, because one of the proposed mechanisms linking dietary glycemic quality to obesity may involve prolonged satiety and reduced energy intakes, energy intakes may lie on the causal pathway, and it may be relevant to explore associations without energy adjustment in addition to those with energy adjustment (12). Heterogeneous results may also be related to differences in the types of foods that contribute to high dietary GI or GL in different contexts (9). In addition to refined cereal products and other starchy staples, certain fruits, vegetables, and legumes may

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make an important contribution to dietary GI and GL in some food cultures. To better understand the relation between dietary GI and GL and obesity, it may be important to examine the food intake patterns underlying high dietary GI and GL.

This analysis examines the relation between dietary GI and GL and BMI in a representative, population-based sample of men and women from the northern Mediterranean coast of Spain. In addition to estimating GI and GL in the habitual diet, we constructed dietary factors that explain variation in GI and GL to identify food patterns that underlie any relation between these measures of carbohydrate quality and BMI. We also examined the effect of adjusting for energy intake—with and without excluding energy intake underreporters—on these relations.

SUBJECTS AND METHODS

Study participants

Data were obtained from 2 population-based cross-sectional surveys conducted in Girona, Spain, in 2000 and 2005 (13). The first survey included 3058 randomly selected, independently living men and women aged 25–74 y. The second survey included 6352 men and women between 35 and 80 y of age. Response rates for the 2 surveys were 71.0% and 71.5%, respectively. All participants from both surveys aged 35–74 y ($n = 8195$) were included in the present analysis. After excluding subjects with extreme BMI values (>60 or <18.5; 1.4%) or energy intakes (<800 or >4500 kcal; 5%), the sample size was 7670. The studies were approved by the Clinical Research Ethical Committee of the Municipal Institute of Health Care, Barcelona, Spain. Participants signed an informed consent, and results of the examination were sent to all participants.

Anthropometric data

Measurements were performed by a team of trained nurses and interviewers who used the same standard methods in the 2 surveys. A precision scale of easy calibration was used for weight measurement, with participants in underwear. Body weight was measured to the nearest 200 g, and height to the nearest 0.5 cm.

Dietary assessment

Dietary intakes were measured by a validated food-frequency questionnaire (14) which was administered by a trained interviewer. We collected usual intakes over the past year by a self-administered food-frequency questionnaire; participants indicated their usual consumption from a 165-item food and beverage list and chose one of 10 frequency categories that ranged from "never or less than one time per month" to "≥6 times per day." Intakes were converted to mean grams per day using standard reference portion sizes. GI for food and beverage items was estimated by using average values from Foster-Powell et al (15), with glucose as the reference food. GI values were available for 56 items, including all carbohydrate-containing foods (ie, foods with ≥5 g carbohydrate per 100 g or 100 mL). The average daily dietary GI was calculated by multiplying the GI of individual foods by the percentage of total energy contributed by carbohydrate $\{\sum[\text{GI food item} \times (\text{grams carbohydrate per serving food item} \times \text{servings consumed per day} \div \text{grams carbohydrate consumed per day})]\}$(16, 17). Dietary GL was calculated by multiplying the daily GI by the amount of carbohydrate consumed and dividing the product by 100 [(daily GI × grams carbohydrate consumed per day) ÷ 100].

Measurement of nondietary variables

Information on demographic and socioeconomic variables, medical history, and lifestyle factors, including tobacco smoking and alcohol consumption, was obtained through structured standard questionnaires administered by trained personnel. Leisure-time physical activity was measured by using the Minnesota Leisure Time Physical Activity Questionnaire, which was also administered by a trained interviewer. This questionnaire has been validated for Spanish men and women (18, 19). Basal metabolic rate was estimated from equations based on sex, age, body weight, and height (20). The cutoff used to identify energy intake underreporters was an energy intake:basal metabolic rate ratio of <1.20, which is consistent with recommended cutoffs in the literature (21). Subjects with energy intake:basal metabolic rate ratios ≥1.20 were classified as plausible reporters.

Statistical analyses

Reduced-rank regression (RRR) was used to extract dietary patterns associated with higher mean dietary GI or GL (22). RRR differs from principal components–based factor analysis methods in that dietary patterns are derived on the basis of their ability to explain variation in specific nutrients or other dietary factors of interest. RRR was used to identify linear functions of foods and food groups that explain as much variation in dietary GI and GL as possible. A detailed description of this method is provided elsewhere (22). RRR analysis was conducted using the partial least-squares option in SAS (PROCPLS, SAS version 9.1; SAS Institute Inc, Cary, NC). Nineteen foods and food groups were included as predictors of consuming high GI or GL diets. Factor loadings, which indicate the magnitude and direction of contributions of each item to the diet pattern scores, are presented, and the proportion of variance explained by items with the highest loadings are described in the text.

Characteristics of the study population associated with dietary glycemic quality were assessed by comparing means (continuous variables) or proportions (categorical variables) across tertiles of GI and GL. The significance of age-adjusted linear trends across GI or GL tertiles was assessed by including GL or GI tertiles as ordinal variables in linear (for continuous variables) or logistic (for categorical variables) regression models, which were adjusted for age. Separate linear regression models were run to examine the relation between BMI and each measure of dietary carbohydrate quality: GI, GL, GI dietary factor, and GL dietary factor. Because associations with BMI were not always linear, dummy variables (GI or GL tertiles) were used in these models. Associations were considered significant at $P < 0.05$. After examining crude associations, we examined the effect of adjusting for leisure-time physical activity, education level, cigarette smoking, alcohol consumption, fiber intakes, and underreporting, with subsequent adjustments for energy. All analyses were conducted separately in men and women.

On the basis of previous reports (5), interactions between underreporting (yes or no) and tertiles of GI, GL, and their respective dietary patterns were examined. Because significant ($P < 0.001$) interactions were found with dietary GL and the GL factor score in both sexes, models for dietary GL and GL factor were stratified by underreporting status. Among underreporter women, the upper 2 tertiles of GL variables were combined in these analyses because there were only 3 women in the top tertiles after stratifying by underreporting status. We also explored interactions between each measure of carbohydrate quality and physical activity (measured as continuous metabolic equivalents); none was significant ($P > 0.10$). In supplementary models, we confirmed that associations between BMI and dietary GI or the GI factor were similar when excluding, rather than adjusting for, underreporting (data not shown). We also confirmed that results were similar for all measures of carbohydrate quality after excluding subjects with diabetes ($n = 853$) who may have changed their diets as a result of their disease status, and after excluding those with impaired fasting glucose (100–125 mg/dL; $n = 2249$) who may experience differential effects of high GL diets (23) (data not shown). Finally, we confirmed that consistent results were observed across different age, physical activity, and Mediterranean diet score strata (data not shown). All analyses were conducted using SAS (version 9.1; SAS Institute Inc).

RESULTS

Characteristics of the sample by dietary GI tertile are described in **Table 1**. A small decline in mean BMI is seen across tertiles of GI in women only ($P = 0.028$). Subjects with higher GI diets also had higher energy intakes, had lower dietary fiber intakes, and were less physically active ($P < 0.05$ for all variables except physical activity in men, $P = 0.276$). Habitual consumption of a high GL diet was associated with lower mean BMI in men and women (**Table 2**; $P = 0.001$ for men, $P < 0.001$ for women). Similar to GI, dietary GL was also associated with higher energy intakes ($P < 0.05$ for both variables). In contrast to GI, however, dietary GL was associated with higher rather than lower intakes of dietary fiber ($P < 0.001$ for both sexes) and with higher rather than lower levels of leisure-time physical activity ($P = 0.001$ for men, $P = 0.015$ for women, for both variables).

Factor loadings for the main food group contributors to the RRR-derived GI and GL dietary patterns in men and women are shown in **Table 3**. Refined bread had the highest loadings for both factors; this item also explained 45.0–67.1% of variance in scores across the different patterns in men and women. French fries and soft drinks also had large positive loadings for both factors but explained a smaller proportion of variance (4.6–7.5% for French fries; 2.5–6.7% for soft drinks). There were marked differences, however, in the relation between the GI and the GL factor for other foods. Fruits, which had the second highest positive loadings for the GL factor, had large negative loadings for the GI factor. Fruit intakes also explained a higher proportion of variance in GL (16.8% and 23.8% in men and women, respectively) than in GI scores (11.0% and 12.0% in men and women, respectively). Similarly, fruit juices (2.3–6.3% of variance in scores), vegetables (2.3–4.6%), legumes (2.7–6.5%), and dairy products (3.1–16.0%) had large positive loadings for the GL pattern but large negative loadings for the GI pattern. Pastries (10.8% of variance in women and 13.8% in men) were positively related to dietary GL only, whereas intakes of whole-grain breads (2.9% of variance in men, 3.9% in women) were negatively related to GI only.

Multivariate-adjusted relations between BMI and dietary GI and the GI factor are shown in **Table 4**. Associations between dietary GI and BMI were weak and nonsignificant ($P > 0.10$) before and after adjusting for energy intakes. The exclusion of underreporters had little effect on associations [in men, energy-adjusted β was 0.114 (95% CI: 0.232, 0.461) for GI tertile 2 and was 0.080 (95% CI: −0.429, 0.269) for GI tertile 3; similar

TABLE 1
Characteristics of study participants according to tertile of dietary glycemic index[1]

	Men				Women			
	First tertile ($n = 1210$)	Second tertile ($n = 1213$)	Third tertile ($n = 1246$)	P[2]	First tertile ($n = 1320$)	Second tertile ($n = 1327$)	Third tertile ($n = 1354$)	P[2]
Glycemic index	52.6 (52.4, 52.8)	58.6 (58.4, 58.8)	65.9 (65.7, 66.1)	—	50.3 (50.1, 50.4)	55.6 (55.5, 55.8)	62.4 (62.3, 62.6)	—
Age (y)	56.3 (55.6, 56.9)	53.5 (52.9, 54.1)	53.6 (53.0, 54.2)	<0.001	56.1 (55.6, 56.7)	53.1 (52.5, 53.7)	52.7 (52.1, 53.2)	<0.001
BMI (kg/m^2)	28.0 (27.8, 28.3)	27.9 (27.6, 28.1)	27.7 (27.5, 27.9)	0.157	27.8 (27.5, 28.1)	26.9 (26.6, 27.2)	26.9 (26.6, 27.2)	0.028
Current smokers (%)	25.5 (22.8, 28.1)	29.8 (27.2, 32.4)	37.8 (35.2, 40.4)	<0.001	12.0 (10.0, 14.0)	16.8 (14.8, 18.8)	20.4 (18.4, 22.4)	0.001
>Primary education (%)	46.9 (44.1, 49.8)	47.9 (45.1, 50.7)	47.4 (44.7, 50.2)	0.194	42.4 (39.7, 45.1)	48.2 (45.5, 50.9)	45.8 (43.1, 48.5)	0.099
Alcohol consumption (g)	13.4 (12.3, 14.4)	16.1 (15.1, 17.2)	19.4 (18.4, 20.5)	<0.001	4.0 (3.5, 4.4)	4.7 (4.3, 5.2)	6.2 (5.5, 8.6)	<0.001
Underreporter (%)[3]	32.2 (29.6, 34.7)	26.4 (23.9, 28.9)	24.3 (21.8, 26.7)	<0.001	17.6 (15.9, 19.4)	9.4 (7.6, 11.2)	10.7 (8.9, 12.5)	<0.001
LTPA (METs · min^{-1} · d^{-1})	384 (362, 405)	377 (356, 398)	353 (332, 373)	0.276	255 (242, 268)	244 (231, 257)	231 (219, 244)	0.031
Energy (MJ)	10.1 (9.9, 10.2)	10.7 (10.6, 10.9)	10.8 (10.7, 11.0)	<0.001	9.7 (9.6, 9.4)	10.5 (10.3, 10.7)	10.4 (10.3, 10.6)	<0.001
Carbohydrate (% kcal)[4]	40.4 (40.0, 40.8)	41.1 (40.7, 41.5)	41.2 (40.8, 41.6)	0.003	42.0 (41.6, 42.4)	41.4 (41.0, 41.8)	41.2 (40.8, 41.6)	0.119
Protein (% kcal)[4]	18.0 (17.8, 18.1)	17.1 (16.9, 17.2)	16.5 (16.4, 16.7)	<0.001	18.9 (18.7, 19.0)	17.8 (17.7,18.0)	17.4 (17.2, 17.5)	<0.001
Fat (% kcal)[4]	40.8 (40.4, 41.1)	40.5 (40.2, 40.9)	40.4 (40.0, 40.7)	0.090	40.6 (40.3, 41.0)	42.1 (41.7, 42.4)	42.4 (42.0, 42.7)	<0001
Dietary fiber (g/4.18 MJ)	12.2 (12.0, 12.4)	10.7 (10.5, 10.9)	9.7 (9.5, 9.9)	<0.001	14.6 (14.4, 14.9)	12.4 (12.2, 12.6)	10.9 (10.7,11.1)	<0.001

[1] Values are means or percentages (95% CIs in parentheses). LTPA, leisure-time physical activity; METs, metabolic equivalents.

[2] For age-adjusted linear trend across GI or GL tertiles.

[3] Energy intake:basal metabolic rate ratio <1.2.

[4] Percentage of energy intake.

TABLE 2

Characteristics of study participants according to tertile of dietary glycemic load[1]

	Men				Women			
	First tertile ($n = 1207$)	Second tertile ($n = 1215$)	Third tertile ($n = 1247$)	P[2]	First tertile ($n = 1324$)	Second tertile ($n = 1316$)	Third tertile ($n = 1361$)	P[2]
Glycemic load	77 (76, 79)	120 (118, 121)	120 (118, 121)	—	72 (71, 73)	111 (110, 112)	166 (165, 167)	—
Age (y)	56.4 (55.8, 57.0)	54.6 (54.0, 55.2)	52.4 (51.8, 53.0)	<0.001	54.9 (54.3, 55.5)	54.3 (53.7, 54.9)	52.6 (52.1, 53.2)	<0.001
BMI (kg/m^2)	28.2 (28.0, 28.4)	27.8 (27.6, 28.1)	27.5 (27.3, 27.7)	0.001	27.7 (27.4, 28.0)	27.2 (26.9, 27.5)	26.7 (26.4, 27.0)	<0.001
Current smoker (%)	31.1 (28.5, 33.8)	30.4 (27.8, 33.0)	31.7 (29.2, 34.3)	0.153	17.8 (15.7, 19.8)	15.4 (13.4, 17.4)	16.4 (14.5, 18.4)	0.004
>Primary education (%)	49.4 (46.6, 52.2)	48.0 (45.2, 50.9)	44.9 (42.2, 47.7)	<0.001	43.7 (41.0, 46.4)	45.1 (42.2, 47.8)	47.5 (44.9, 50.2)	0.885
Alcohol consumption (g)	16.4 (15.3, 17.4)	16.3 (15.2, 17.3)	16.6 (15.5, 17.6)	0.881	5.0 (4.5, 5.4)	5.1 (4.7, 5.6)	4.8 (4.4, 5.2)	0.299
Underreporter (%)[3]	58.6 (56.4, 60.7)	21.6 (19.4, 23.7)	3.4 (1.2, 5.5)	<0.001	33.2 (31.6, 34.8)	4.2 (2.6, 5.8)	0.6 (−1.0, 2.2)	<0.001
LTPA (METs $\cdot$ min^{-1} $\cdot$ d^{-1})	353 (331, 374)	380 (359, 402)	380 (359, 402)	0.001	235 (221, 248)	240 (227, 253)	256 (243, 269)	0.015
Energy (MJ)	8.1 (8.0, 8.2)	10.4 (10.3, 10.5)	13.1 (13.0, 13.2)	<0.001	7.8 (7.7, 7.9)	10.1 (9.9, 10.2)	12.7 (12.6, 12.9)	<0.001
Carbohydrate (% kcal)[4]	36.9 (36.6, 37.3)	41.0 (40.7, 41.4)	44.7 (44.3, 45.0)	<0.001	37.7 (37.3, 38.0)	41.5 (41.1, 41.8)	45.4 (45.0, 45.7)	<0.001
Protein (% kcal)[4]	18.0 (17.9, 18.1)	17.2 (17.0, 17.3)	16.3 (16.2, 16.5)	<0.001	19.1 (18.9, 19.3)	17.9 (17.7,18.0)	17.1 (16.9, 17.3)	<0.001
Fat (% kcal)[4]	42.6 (42.2, 42.9)	40.6 (40.3, 42.0)	38.6 (38.3, 39.0)	<0.001	43.9 (43.6, 44.3)	41.9 (41.5, 42.3)	39.3 (38.9, 39.6)	<0001
Dietary fiber (g/4.18 MJ)	10.5 (10.3, 10.8)	10.8 (10.6, 11.0)	11.1 (10.9, 11.3)	<0.001	12.2 (12.0, 12.5)	12.5 (12.3, 12.7)	13.2 (12.9,13.4)	<0.001

[1] Values are means or percentages (95% CIs in parentheses). LTPA, leisure-time physical activity; METs, metabolic equivalents.

[2] For age-adjusted linear trend across GI or GL tertiles.

[3] Energy intake:basal metabolic rate ratio <1.2.

[4] Percentage of energy intake.

results in women are not shown]. For the GI factor, associations were also largely weak and nonsignificant, with the exception of a significant decrease in mean BMI among women in the second (multivariate-adjusted $P = 0.011$ with or without energy intakes) but not the third tertile ($P = 0.268$) compared with women in the lowest tertile.

To take into account interactions with underreporting (interaction $P < 0.001$ for both sexes), associations between BMI and measures of GL were stratified by underreporting (**Table 5**). Among plausible reporters, multivariate-adjusted associations between BMI and dietary GL and the GL factor were null before adjusting for energy ($P > 0.05$ for both sexes). After adjusting for energy, however, dietary GL and the GL factor were associated with significant ($P < 0.05$) declines in BMI. The adjusted mean difference in BMI between the highest and lowest GL tertile was −0.71 kg/m^2 ($P < 0.05$) for women and −0.43 kg/m^2 ($P < 0.10$) for men; for the GL factor, these differences were −0.76 kg/m^2 ($P < 0.05$) for women and −0.52 kg/m^2 ($P < 0.05$) for men.

In contrast, among underreporters, there was a positive relation between BMI and high dietary GL ($P < 0.002$ for men, $P = 0.178$ for women) and the GL factor ($P < 0.001$ for men, $P = 0.025$ for women) in models excluding energy intakes. After adjusting for energy intakes, these associations were substantially attenuated. Indeed, associations with dietary GL became null or inverse after adjusting for energy. For the GL factor, however, the adjusted mean difference BMI remained positive and significant among underreporter men in the top compared with the bottom GL tertile after adjusting for energy (adjusted mean difference: 1.71 kg/m^2, $P = 0.019$). Associations among women were null, perhaps as a consequence of small cell size ($n = 63$ underreporter women in the second or third GL tertile).

DISCUSSION

To our knowledge, this is the first epidemiologic study on dietary glycemic quality and BMI conducted in a Mediterranean population. In this population of Spanish adults, dietary GI was not associated with BMI in the sample as a whole or after excluding underreporters. There was no meaningful effect of adjusting for energy intakes on associations with GI. In contrast, dietary GL, which takes into account the amount and the quality of carbohydrate, was negatively associated with BMI among subjects with plausible intakes in energy-adjusted models. When energy intake adjustment was excluded, the associations between dietary GL and BMI were null among subjects who reported plausible levels of energy intake.

To better understand the intake patterns underlying these associations, we used RRR to construct dietary pattern factor scores related to variability in GI and GL. Consistent with findings for GI and GL, after energy adjustment the GL factor was negatively associated with BMI among subjects with plausible intakes, with null associations for the GI factor. More important, the factor loadings illustrated important differences in the food intakes that characterized subjects with high GL compared with those with high GI diets. Although some foods—including refined bread and French fries—had similar positive loadings for both factors, fruits, vegetables, and legumes had large positive loadings for the GL factor but large negative loadings for the GI factor. Similar patterns related to GI and GL have been reported elsewhere (24–26). Moreover, the inverse energy-adjusted associations between BMI and dietary GL, but not GI, are consistent with higher intakes of the foods with discrepant loadings that tend to be high in fiber and low in energy density (27, 28).

Contrary to our findings, it has generally been postulated that there may be a positive relation between glycemic quality of diet

TABLE 3

Factor loadings for glycemic index and glycemic load diet pattern scores[1]

Food	Glycemic index pattern factor loading		Glycemic load pattern factor loading	
	Men	Women	Men	Women
Cereal products and potatoes				
Refined bread	0.73[2]	0.70[2]	0.63[2]	0.56[2]
Pastries	—	—	0.32[2]	0.27[2]
French fries	0.19	0.24	0.24	0.21
Whole-grain bread	−0.15	−0.17	—	—
Rice and pasta	−0.12	—	0.23	0.23
Cooked potatoes	—	—	0.16	0.24
Fruits, vegetables, and legumes				
Fruits	−0.30[2]	−0.30[2]	0.35[2]	0.40[2]
Legumes	−0.16	−0.14	0.17	0.21
Other vegetables	−0.14	−0.19	0.14	0.17
Fruit juices	−0.14	—	0.13	0.21
Cruciferous vegetables	−0.10	−0.11	—	—
Dairy products				
Low-fat milk and yogurt	−0.20	−0.34[2]	—	—
High-fat milk and yogurt	−0.33[2]	—	0.15	0.18
Other foods				
Red meat and sausages	0.15	0.17	0.20	0.19
Fish	—	—	0.11	0.12
White meat	−0.10	—	—	—
Chocolate	—	—	0.11	—
Olive oil	—	—	—	0.10
Soft drinks	0.14	0.19	0.22	0.17

[1] Factor loadings between −0.09 and +0.09 not shown. Reduced-rank regression was used to derive dietary patterns associated with mean daily glycemic index or mean daily glycemic load.

[2] Top 3 factor loadings for glycemic index and glycemic load patterns.

and obesity (1–3, 29). Numerous previous epidemiologic studies on dietary GL, however, are consistent with negative or null associations with BMI in adults. Inverse associations between energy-adjusted dietary GL and BMI, waist circumference, or waist:hip ratio have been reported in recent studies (9, 30) and in previously reviewed descriptive data from 6 of 8 large cohort studies that focused on other outcomes; none suggested a positive relation (8). Studies focused specifically on obesity have reported predominantly null associations between GL and BMI (4, 11) or weight gain (10); one study reported a weak positive association that was completely attenuated after adjusting for energy (7). Similarly, results are heterogeneous for dietary GI, with slightly more reports of null or negative (7–10) than of positive (4–6) relations. Indeed, when our survey samples were examined separately, the weak negative association between GI and BMI reached significance in the later survey ($\beta = -0.315$; 95% CI: −0.608, −0.021) for GI tertile 3], with a null association in the earlier sample ($\beta = 0.070$; 95% CI: −0.379, 0.520) in models that included energy. Although reasons for this difference are unclear, neither sample suggests a positive or strong relation between GI and BMI. For dietary GL, significant negative associations with BMI were found in both samples (data not shown).

Positive associations between BMI and dietary GL have been reported after adjustment in models including energy intakes in at least 2 previous studies (5, 6). In one of these, a Danish study, initially negative associations became positive after adjusting for energy intakes or limiting the sample to plausible reporters (5). In contrast, in our analysis initially null associations among plausible reporters became negative after adjusting for energy intakes. Reasons for these disparate results are uncertain. One possibility may be heterogeneity in intake patterns underlying dietary GL (9), such as the relatively higher intakes of fruits, vegetables, and legumes in this Mediterranean population (combined intakes of fruits and vegetables of 679 g and 801 g in men and women, respectively) compared with the Danish sample (mean intakes of 182 g and 302 g in men and women, respectively) (31). Other previous epidemiologic studies on dietary glycemic quality and obesity have been conducted in the United States, the United Kingdom, Japan, and western Europe, settings where intakes of these foods and likely their contribution to dietary GL is generally lower than in the Mediterranean region (32). Despite possible heterogeneity in underlying intakes, however, mean ± SD dietary GI in women and men (56.2 ± 5.7 and 59.2 ± 6.3, respectively) and dietary GL (116.7 ± 44.5 and 125.7 ± 48.1, respectively) in our sample were similar to values reported in other studies conducted in diverse settings with glucose as the reference standard [eg, GI of 58.0 ± 4.0 and GL of 128.3 ± 55.9 (7); GI of 55.8 ± 4.0 in women and 56.8 ± 4.2 in men and GL of 118.3 ± 49.6 in women and 145.2 ± 61.3 in men (11); and GI of 65.1 ± 4.3 (6)]. Another possible contributor to heterogeneous results may be population differences in insulin metabolism: a recent trial in obese adults suggested that low GL diets may promote weight loss in insulin-sensitive subjects only (23). Excluding subjects with impaired fasting glucose who may have reduced insulin sensitivity, however, had no meaningful effect (data not shown).

Mechanisms through which higher GI or GL is hypothesized to increase obesity risk are related to hyperinsulinemia, which may promote reduced fat oxidation and greater carbohydrate oxidation, potentially leading to greater storage of fat (1, 3), although evidence that these metabolic changes occur is equivocal (33, 34). Others have suggested that an important mechanism may involve reduced blood glucose fluctuations, leading to prolonged satiety and lower energy intakes, which suggests that energy adjustment may eliminate associations with GI or GL (1–3, 12). A recent meta-analysis that shows that dietary GL is associated with weight loss only in trials with no or limited control of energy intakes is consistent with mechanisms involving reduced energy intakes (35). Nonetheless, in models that excluded adjustment for energy intakes, dietary GL or GI was not associated with higher BMI despite being associated with higher energy intakes. In energy-adjusted relations, which were examined because it has been argued that energy adjustment is necessary to approximate isocaloric replacement of other types of macronutrients (5), dietary GL and the GL dietary factor were associated with lower BMI.

An important limitation of this study is its cross-sectional nature: we were unable to assess associations with weight change, for which there are limited data (10). Results of weight loss trials to date have been heterogeneous (35), including several conducted in Mediterranean countries (36–38). Beneficial effects reported in one trial appeared largely attributable to lower energy and higher fiber intakes in the low-GI group (38). We were also unable to assess associations with central fatness or direct measures of adiposity because these data were not

TABLE 4

Multivariate-adjusted associations between BMI and glycemic index (GI) and GI factor score

	n	Model 1 coefficient[1]	95% CI	*P*	Model 2 coefficient[2]	95% CI	*P*
Dietary GI							
Men[3]							
Second tertile	1213	0.109	−0.193, 0.411	0.478	0.014	−0.287, 0.316	0.926
Third tertile	1246	0.009	−0.314, 0.411	0.955	−0.137	−0.443, 0.169	0.381
Women[3]							
Second tertile	1327	−0.185	−0.547, 0.177	0.316	−0.285	−0.649, 0.078	0.124
Third tertile	1354	−0.103	−0.472, 0.267	0.586	−0.249	−0.624, 0.125	0.192
GI factor score							
Men[3]							
Second tertile	1210	−0.043	−0.343, 0.258	0.782	−0.077	−0.376, 0.223	0.615
Third tertile	1246	0.043	−0.265, 0.352	0.782	−0.149	−0.461, 0.164	0.351
Women[3]							
Second tertile	1321	−0.459	−0.827, -0.092	0.015	−0.480	−0.848, −0.112	0.011
Third tertile	1360	−0.083	−0.458, 0.293	0.666	−0.294	−0.594, 0.165	0.268

[1] Model 1 shows results of multivariate linear regression adjusted for age, leisure-time physical activity, educational level, smoking, alcohol consumption, dietary fiber, and underreporting.

[2] Model 2 shows results adjusted for the variables in model 1 in addition to energy intakes.

[3] First tertile = referent.

available. One previous study reported negative associations between GL and visceral abdominal fat in men despite null associations with BMI (11). Nonetheless, this study has several important strengths, including the fact that it analyzed a large population-based sample with measured anthropometry, and possible effects of energy underreporting were taken into account.

In conclusion, despite evidence of benefits for other outcomes (35, 39), our results do not support the hypothesis that high GI or

TABLE 5

Multivariate-adjusted association between body mass index and glycemic load (GL) and GL factor score among energy intake underreporters and plausible reporters[1]

	n	Model 1 coefficient[2]	95% CI	*P*	Model 2 coefficient[3]	95% CI	*P*
Dietary GL							
Men, plausible reporters[4]							
Second tertile	953	0.146	−0.248, 0.593	0.469	−0.037	−0.437, 0.362	0.885
Third tertile	1205	0.089	−0.318, 0.495	0.668	−0.427	−0.885, 0.032	0.068
Women, plausible reporters[4]							
Second tertile	1261	0.111	−0.281, 0.502	0.579	−0.101	−0.504, 0.301	0.622
Third tertile	1353	−0.140	−0.559, 0.279	0.512	−0.707	−1.200, −0.213	0.005
Men, underreporters[4]							
Second tertile	262	0.118	−0.473, 0.709	0.696	−0.704	−1.350, 0.117	0.020
Third tertile	42	2.031	0.758, 3.305	0.002	0.531	−0.786, 1.831	0.422
Women, underreporters[4]							
Second/third tertile	63	1.022	−0.468, 2.511	0.178	−0.539	−1.971, 0.893	0.460
GL factor							
Men, plausible reporters[4]							
Second tertile	947	−0.018	−0.413, 0.376	0.928	−0.200	−0.600, 0.200	0.328
Third tertile	1211	0.014	−0.388, 0.417	0.945	−0.525	−0.984, −0.067	0.025
Women, plausible reporters[4]							
Second tertile	1265	0.205	−0.187, 0.597	0.305	0.028	−0.435, 0.377	0.843
Third tertile	1352	−0.133	−0.547, 0.282	0.503	−0.762	−1.259, −0.264	0.003
Men, underreporters[4]							
Second tertile	263	0.595	0.012, 1.178	0.045	−0.157	−0.770, 0.456	0.616
Third tertile	53	3.148	1.753, 4.543	<0.001	1.712	0.281, 3.143	0.019
Women, underreporters[4]							
Second/third tertile	62	1.778	0.225, 3.531	0.025	0.306	−1.187, 1798	0.687

[1] Plausible reporters were defined as subjects with energy intake:basal metabolic rate ratio $\geq$1.2; underreporters were defined as subjects with energy intake:basal metabolic rate ratio $<$1.2.

[2] Model 1 shows results of multivariate linear regression adjusted for age, leisure-time physical activity, educational level, smoking, alcohol consumption, and dietary fiber.

[3] Model 2 shows results adjusted for variables in model 1 in addition to energy intakes.

[4] First tertile = referent.

GL is positively related to obesity. Rather, they suggest that in a Mediterranean food culture context, a diet characterized by higher GL may be associated with lower BMI. Underreporting did not explain the inverse energy-adjusted relation between dietary GL and BMI, which was observed in subjects with plausible energy intakes. Further research in other populations with different intake patterns, using longitudinal data on weight change, is needed to elucidate any independent effects of dietary GL or GI on obesity.

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