A High Dietary Glycemic Index Increases Total Mortality in a Mediterranean Population at High Cardiovascular Risk

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Abstract

Objective: Different types of carbohydrates have diverse glycemic response, thus glycemic index (GI) and glycemic load (GL) are used to assess this variation. The impact of dietary GI and GL in all-cause mortality is unknown. The objective of this study was to estimate the association between dietary GI and GL and risk of all-cause mortality in the PREDIMED study.

Material and Methods: The PREDIMED study is a randomized nutritional intervention trial for primary cardiovascular prevention based on community-dwelling men and women at high risk of cardiovascular disease. Dietary information was collected at baseline and yearly using a validated 137-item food frequency questionnaire (FFQ). We assigned GI values of each item by a 5-step methodology, using the International Tables of GI and GL Values. Deaths were ascertained through contact with families and general practitioners, review of medical records and consultation of the National Death Index. Cox regression models were used to estimate multivariable-adjusted hazard ratios (HR) and their 95% CI for mortality, according to quartiles of energy-adjusted dietary GI/GL. To assess repeated measures of exposure, we updated GI and GL intake from the yearly FFQs and used Cox models with time-dependent exposures.

Results: We followed 3,583 non-diabetic subjects (4.7 years of follow-up, 123 deaths). As compared to participants in the lowest quartile of baseline dietary GI, those in the highest quartile showed an increased risk of all-cause mortality [HR = 2.15 (95% CI: 1.15–4.04); P for trend = 0.012]. In the repeated-measures analyses using as exposure the yearly updated information on GI, we observed a similar association. Dietary GL was associated with all-cause mortality only when subjects were younger than 75 years.

Conclusions: High dietary GI was positively associated with all-cause mortality in elderly population at high cardiovascular risk.


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Data Availability: The authors confirm that all data underlying the findings are fully available without restriction. All relevant data are within the paper.

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**Introduction**

The epidemiological transition and increased prevalence of chronic-degenerative diseases in the elderly population is related to nutritional status. In Spain, 35% of the population aged 65 years or more is obese [1]. Obesity, especially visceral obesity, confers an increased risk of mortality not only from cardiovascular diseases (CVD) but also from other causes such as cancer or diabetes and its complications [2].

Currently, dietary recommendations from FAO and WHO to prevent chronic diseases are aimed to reduce or change the proportion of fats to a healthier profile, while increasing the carbohydrate content of the diet [2–5]. Although these recommendations establish a limit in the intake of free sugars and suggest the ideal amount of fiber consumption, they are not specific in relation to the quality of the dietary carbohydrates [2–5]. New evidence-based recommendations from the WHO are being prepared and probably further adjustments will be made regarding the proportion of fat and sugar intake. However, both the quality and the amount of carbohydrates, generate different responses of insulin secretion and postprandial glucose [6]. Thus, Jenkins et al. [7] introduced the concept of glycemic index (GI). GI is defined as the postprandial blood glucose response of a test food, compared to the response of the same amount of available carbohydrate in a reference food consumed by the same subject. Similarly, glycemic load (GL) evaluates the overall glycemic effect of the diet, multiplying the glycemic index of the diet by the content of total carbohydrates consumed by the individual [8]. Dietary GI and GL were developed to measure the average daily consumption of an individual in terms of quality and amount of available carbohydrates [9].

Current research has evaluated the relationship between dietary GI and GL in the prevention and study of obesity, CVD, cancer and many other health problems, such as macular degeneration [6,9–12].

The literature to confirm the relationship between GI and GL for overall fatal events is scarce. In fact, usually, references are related to specific causes of fatal events such as cancer [13] and cardiovascular disease mortality [14,15]. The association between dietary GI and GL and the risk of total mortality has been investigated in men with established CVD [16] and breast cancer survivors [17], but no significant associations were found between all-cause mortality when comparing the highest intakes of dietary GI and GL vs. the lowest. Furthermore, an association between higher intake of dietary GL and risk for all-cause mortality has been found in diabetic subjects with normal weight [18]. Similarly, Baer et al. [19] found a relationship in women aged 30–55 years: an increase of 41 units of GL, augment by 22% the risk for total mortality.

The association between GI/GL and all-cause mortality is still unclear; therefore, we aimed to evaluate the association of the quality of carbohydrates on all-cause mortality in an elderly population at high cardiovascular risk.

**Materials and Methods**

**Study design**

This study was conducted within the frame of the PREDIMED study (PREvención con DIeta MEDiterránea), a randomized, multicenter, parallel group, single-blinded dietary intervention trial conducted in Spain (Trial Registration: clinicaltrials.gov Identifier: ISRCTN35739639) [20]. The main objective of the trial was to analyze the effect of the Mediterranean Diet (MeDiet) on major cardiovascular disease prevention when comparing to a control diet [20]. Participants were randomly assigned to three groups: MeDiet supplemented with extra virgin olive oil (MeDiet + EVOO), MeDiet with nuts (MeDiet + nuts), and the control group. Participants received dietary training without calorie restriction or advice on physical activity [20]. After the completion of the trial, the PREDIMED study provided an opportunity for conducting the long-term follow-up of a large observational cohort of high cardiovascular risk subjects in a Mediterranean setting [21]. The design of the PREDIMED study has been reported in detail elsewhere [21]. The protocol was approved by the institutional review boards of each recruitment center and all participants provided a written informed consent prior to their inclusion in the study.

**Study population**

The PREDIMED study included 7447 participants, aged between 55 and 80 years. Subjects without prior CVD were selected when they met at least one of the following criteria: presence of type 2 Diabetes Mellitus (T2DM) or the presence of three or more cardiovascular risk factors (current smoking, hypertension, high LDL cholesterol (≥160 mg/dl), low HDL cholesterol (≤40 mg/dl in men and ≤50 mg/dl in women), overweight or obesity (BMI≥25 kg/m²), or family history of premature CVD).

For this analysis, we selected participants without T2DM at baseline (n = 3833). Exclusion criteria were: subjects without follow-up (n = 125), with values of total energy intake outside of predefined limits (<800 or>4000 kcal/d in men and: <300 or>3500 kcal/d in women) (n = 86), use of anti-diabetic medication (n = 21) and incomplete data in any variable used in the analyses (n = 18). Overall, 3,583 subjects were analyzed in this study. The rationale for exclusion of persons with a baseline history of diabetes mellitus (including type 1 diabetes, T2DM or use of anti-diabetic medication) was potential effect modification and potential changes in the diet as a result of diagnosis and treatment of T2DM.

**Dietary assessment**

Trained dietitians used a 137–item food frequency questionnaire (FFQ) to assess dietary habits by face-to-face interviews. This FFQ was repeatedly administered each year during follow-up. The FFQ has been validated in a sample of subjects with similar characteristics to the participants of the PREDIMED study [22]. Energy (kcal/day) and nutrient intake (g/day) were calculated as frequency multiplied by nutrient composition of specified portion size where frequencies were measured in nine categories for each food item. Nutrient data bank was updated using the latest available information included in food composition tables for Spain [23]. Alcohol intake was also ascertained through the use of this questionnaire. Carbohydrates, proteins, fat and dietary fiber intakes, GI and GL were adjusted for total energy intake using the residual method proposed by Willet [24].
Estimation of dietary GI and GL

We assigned the GI of each food of the FFQ using Louie et al. protocol [25] with the International Tables of GI and GL values [26] and the Sydney University GI research service [27]. Values were extracted from published studies conducted in normal subjects, using glucose as reference food [26].

After the GI assignment, we estimated dietary GI for each individual summing the GI of each food multiplied by the amount of available carbohydrate consumed (g/day) and divided by the total available carbohydrate amount. For dietary GL, the sum of the GI multiplied by the amount of available carbohydrate consumed was divided by 100 [28]. Energy-adjusted dietary GI and GL intake was finally categorized into quartiles. To assess the repeated measurements of diet, we updated GI and GL values from the yearly FFQs.

Outcome ascertainment

All-cause mortality was determined by review of the End Point adjudication Committee. This panel was blinded to the intervention group. Information on all-cause mortality was updated on a yearly basis. Information on the occurrence of each fatality was initially obtained from the continuous contact with participants and their families that we had during the trial, contact with family physicians, the yearly comprehensive review of all medical records and by yearly consultation of the National Death Index. The analyses included cases confirmed between October 1st, 2003, and December 1st, 2010.

Statistical analysis

Baseline characteristics of the population and dietary intakes were calculated according to quartiles of dietary GI and GL. Follow up time was calculated from the date of recruitment to the date of either death or end of follow-up (the date of the last visit or the last recorded clinical event of participants still alive). Different Cox regression models were used to estimate multivariable-adjusted hazard ratios (HR) and their 95% CI for all-cause mortality according to baseline quartiles of energy adjusted dietary GI and GL. A first model was adjusted for sex, age (years), recruitment center and intervention group (Med Diet + EVOO, Med Diet + Nuts and control diet). A second model was further adjusted for potential confounders including: smoking (never, past, current), education (low, middle, high, no data available), marital status (married, other), physical activity (continuous), BMI (continuous), self-reported history of cancer (yes, no), self-reported history of arterial hypertension (yes, no), self-reported history of cardiovascular disease (yes, no), total energy intake (continuous), alcohol intake (continuous) and dietary fiber intake (continuous, energy adjusted). The third model was further adjusted for saturated fatty acids (continuous, energy adjusted) and monounsaturated fatty acids (continuous, energy adjusted). In all the analyses, recruitment center was entered into the model through the strata statement. Tests of linear trend across increasing quartiles of GI and GL were conducted by assigning the medians to each quartile and these variables were treated as continuous in the multivariate models. To assess a possible interaction between dietary GI/GL and sex or intervention group, we introduced product terms in the different multivariable models and considered $p<0.05$ in the likelihood ratio test as statistically significant.

To update GI and GL intake with all available longitudinal data, we used Cox regression models with time-dependent exposures. Three models were adjusted using the same covariates used for the models of baseline analysis. For dietary measures, we used the cumulative average of food intakes from baseline to the censoring events. BMI and physical activity were also yearly updated. Because changes in diet after development of diabetes may confound the association between exposure and mortality [31], we stopped updating dietary variables at the time interval during which individuals developed T2DM.

Finally, sensitivity analyses were conducted using quartiles of energy-adjusted GI and GL specific for different groups of the population to observe the effect of changing energy limits (percentiles 1 and 99, percentiles 5 and 95), including population with T2DM, excluding obese subjects (BMI≥30 kg/m²) and including only obese subjects, excluding participants with more than 6 years of follow-up and exclusion of subjects aged 75 years or more. Statistical analyses were performed using Stata 12.0 (StataCorp, College Station, TX, USA) and the significance level was set at $p<0.05$.

Results

In this study, participants were followed for a median of 4.7 years. Of 3,583 subjects, 123 cases of all-cause mortality were registered. The mean (SD) dietary GI and GL of participants at recruitment was 57.6 (4.7) and 117.6 (24.1) respectively. Table 1 shows the main baseline characteristics of the population according to energy adjusted dietary GI and GL quartiles.

In the first model, subjects in the top quartile of dietary GI differed from the individuals in the lowest quartile in that they were younger and more often male, were more likely to be current smokers and more likely to be married. Participants in the highest quartile of dietary GI also had slightly lower BMI (−0.6 kg/m²), higher consumption of alcohol and carbohydrate but less intake of protein, fat and dietary fiber than the subjects in the bottom quartile of dietary GI. Characteristics according to dietary GI were similar to GI excepting that subjects in the highest quartile of GI were more often female, older, less likely to be current smokers, more likely to have only primary education, less likely to be married and physically active, had lower alcohol consumption, lower energy intake had higher intake of fiber when compared to the lowest quartile. The proportion of prevalent diseases such as cancer or arterial hypertension was similar across quartiles of dietary GI and GL. According to intervention group, mean dietary GI and GL were significantly higher when comparing the highest quartiles vs. the lowest.

We found a significant association between the highest quartile of dietary GI and all-cause mortality (Table 2). In the first model, subjects in the top quartile of baseline dietary GI had a 2.2 fold risk of all-cause mortality vs. subjects in the lowest quartile [HR = 2.22 (95% CI: 1.26–3.94); $p$ for trend = 0.002]. After multivariable adjustment, this association was attenuated but remained significant [HR = 2.15 (95% CI: 1.15–4.04); $P$ for trend = 0.012]. Our results revealed a higher risk for all cause mortality and baseline dietary GI in the multivariate analysis although it did not reach statistical significance [HR = 1.95 (95% CI: 0.97–3.90); $p$ for trend = 0.072]. No significant interactions with sex or intervention group were
### Table 1. Characteristics of non diabetic subjects in the PREDIMED study assessed at baseline according to quartiles of energy adjusted dietary glycemic index and dietary glycemic load<sup>1, 2</sup>.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Energy adjusted dietary glycemic index</th>
<th>Energy adjusted dietary glycemic load</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td></td>
<td>n = 896</td>
<td>n = 896</td>
</tr>
<tr>
<td><strong>Demographic characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sex (% Female)</strong></td>
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<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>66.8±5.9</td>
<td>67.0±6.2</td>
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<tr>
<td>Smoking (%)</td>
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<tr>
<td><strong>Education (%)</strong></td>
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<tr>
<td>Elementary school</td>
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<td>73.8</td>
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<tr>
<td>Secondary school</td>
<td>5.6</td>
<td>17.0</td>
</tr>
<tr>
<td>Graduate school</td>
<td>8.4</td>
<td>7.4</td>
</tr>
<tr>
<td>No data available</td>
<td>2.1</td>
<td>1.9</td>
</tr>
<tr>
<td><strong>Marital status (% Married)</strong></td>
<td></td>
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<tr>
<td>Physical activity (METs-h/w)</td>
<td>233.3±229.4</td>
<td>227.2±237.1</td>
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<tr>
<td>BMI (kg/m²)</td>
<td>30.3±3.7</td>
<td>30.1±3.6</td>
</tr>
<tr>
<td>Cancer (%)</td>
<td>3.6</td>
<td>2.7</td>
</tr>
<tr>
<td>Arterial hypertension (%)</td>
<td>91.6</td>
<td>92.0</td>
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<tr>
<td>Alcohol intake (g/d)</td>
<td>6.0±11.2</td>
<td>7.5±12.7</td>
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<td><strong>Dietary intake</strong></td>
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</tr>
<tr>
<td>Total energy intake (kcal/d)</td>
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<td>2251±525</td>
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<tr>
<td>Carbohydrate intake (g/d)</td>
<td>2353±39.1</td>
<td>2418±39.1</td>
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<tr>
<td>Protein intake (g/d)</td>
<td>95.6±14.0</td>
<td>91.4±12.9</td>
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<tr>
<td>Fat intake (g/d)</td>
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<td>98.6±168</td>
</tr>
<tr>
<td>Monounsaturated fatty acids (g/d)</td>
<td>49.3±10.7</td>
<td>48.9±11.4</td>
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<tr>
<td>Polyunsaturated fatty acids (g/d)</td>
<td>16.0±5.3</td>
<td>15.8±4.8</td>
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<tr>
<td>Saturated fatty acids (g/d)</td>
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<td>25.0±5.6</td>
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<tr>
<td>Dietary fiber intake (g/d)</td>
<td>27.6±8.2</td>
<td>26.5±7.6</td>
</tr>
<tr>
<td>GI (per day)</td>
<td>51.7±2.2</td>
<td>55.9±0.9</td>
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<tr>
<td>Mean GI ‡ (SD) according to intervention group</td>
<td></td>
<td></td>
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<tr>
<td>Mediterranean Diet + EVOO</td>
<td>51.4±2.3</td>
<td>55.9±1.0</td>
</tr>
<tr>
<td>Mediterranean Diet + Nuts</td>
<td>51.8±2.2</td>
<td>55.9±0.9</td>
</tr>
</tbody>
</table>

<sup>1</sup> GI: Glycemic Index; GL: Glycemic Load

<sup>2</sup> Mean GI and GL values are reported as mean ± standard deviation (SD).

<sup>3</sup> Mean GI and GL values are reported as mean ± standard error (SE).

<sup>4</sup> Mean GI and GL values are reported as mean ± standard mean error (SME).

<sup>5</sup> Mean GI and GL values are reported as mean ± standard error of the mean (SEM).

<sup>6</sup> Mean GI and GL values are reported as mean ± standard deviation of the mean (SDM).

<sup>7</sup> Mean GI and GL values are reported as mean ± standard error of the mean (SEM).
observed. In the repeated measurement analyses using as exposure the yearly updated information on GI, we found a significant association with all-cause mortality [HR = 2.25 (95% CI: 1.16–4.36) for the highest versus the lowest quartile; p for trend = 0.014]. Regarding updated dietary GL, we observed that subjects in the top quartile had around 75% higher risk for mortality when compared to those in the bottom quartile, however, this association did not achieve statistical significance.

Results from sensitivity analyses comparing the risk of mortality between the upper quartiles (quartile 3 and quartile 4) of GI and GL with reference to the lowest quartile are shown in Table 3. We also found positive associations between the upper quartile of dietary GI with all-cause mortality when considering energy limits as percentiles 1 and 99 or percentiles 5 and 95, and in subjects younger than 75 years. Finally, obese subjects in the top quartiles of dietary GI presented a 3-fold increased risk for all-cause mortality with a statistically significant positive trend (p for trend = 0.044). Dietary GL was associated with all-cause mortality when we excluded participants with total energy intake lower than percentile 1 or higher than percentile 99 [HR = 2.10 (95% CI: 1.03–4.27) for the highest versus the lowest quartile; p for trend = 0.042] and when we restricted the analysis to subjects younger than 75 years [HR = 3.16 (95% CI: 1.32–7.54); p for trend = 0.019].

Discussion

We found that higher intake of baseline dietary GI was associated with an increased risk of all-cause mortality in 3,583 non-diabetic elderly subjects. This association remained significant in the repeated measurement analysis. With respect of dietary GL, we observed a higher risk of all-cause mortality only in subjects at high risk of CVD younger than 75 years.

Our results differ from a cohort of Swedish men, aged from 45 to 79 years with prior cardiovascular disease, where no association was found between dietary GI nor GL and all-cause mortality [16]. We did not find a relationship for all-cause mortality and dietary GL for the original sample evaluated; however, the association was statistically significant for subjects younger than 75 years. This effect is similar to the Nurses’ Health Study, where GL was identified as a risk factor for all-cause mortality among 50,112 women aged 30–55 years [19]. It is of interest to note that in the Nurses’ Health study a significant association was found with “other causes” but not with CHD and cancer mortality. Therefore, the differences could be explained because our study was conducted in aged population at high cardiovascular risk and our endpoint incorporated all causes of death, including CHD and cancer.

Our results also agree with a previous study where Oba et al. reported an association of similar magnitude between dietary GI and mortality from stroke risk in women. No associations were observed between dietary GL and the risk of total stroke or death from ischemic stroke [15]. A positive trend was found for GL and death from hemorrhagic stroke in women. In our study, a significant trend was found in the sensitivity analysis only in subjects younger than 75 years. When individuals over 75 years were analyzed, no associations were found between dietary GI nor GL with all cause mortality (data not shown). This fact reflects that the oldest subjects in our sample could be attenuating our results due to age-related influences, such as deterioration in glucose metabolism. Pancreatic, insulin receptor, and post-receptor changes associated with aging are critical components of the endocrinology of aging. Apart from decreased (relative) insulin secretion by the β cells, peripheral insulin resistance related to

<table>
<thead>
<tr>
<th>Table 1. Cont.</th>
<th>Energy adjusted dietary glycemic index</th>
<th>p-value</th>
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<tbody>
<tr>
<td>Variables</td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td>Control group</td>
<td>n = 896</td>
<td>n = 896</td>
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<tr>
<td>Energy adjusted dietary glycemic index</td>
<td>51.8±2.0</td>
<td>56.0±0.9</td>
</tr>
<tr>
<td>Energy adjusted dietary glycemic load</td>
<td>6.8±3.2</td>
<td>6.8±3.2</td>
</tr>
</tbody>
</table>

- Data are presented as mean ± SD for quantitative variables and as percentages for qualitative variables, n = 3604.
- Abbreviations: n, number of subjects; Q, quartile; MET, metabolic equivalent; BMI, body mass index; GI, dietary glycemic index; GL, dietary glycemic load.
- Values are adjusted for energy using the residuals method.
<table>
<thead>
<tr>
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<th>Baseline energy adjusted dietary glycemic index</th>
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<tr>
<td></td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>Median</td>
</tr>
<tr>
<td></td>
<td>52.1</td>
<td>55.9</td>
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<tr>
<td>Cases</td>
<td>17</td>
<td>23</td>
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<tr>
<td>Person-years</td>
<td>3797</td>
<td>3830</td>
</tr>
<tr>
<td>HRb (95% CI)</td>
<td>1 (Ref.)</td>
<td>1.17 (0.62–2.19)</td>
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<tr>
<td>HRc (95% CI)</td>
<td>1 (Ref.)</td>
<td>1.30 (0.68–2.49)</td>
</tr>
<tr>
<td>HRd (95% CI)</td>
<td>1 (Ref.)</td>
<td>1.36 (0.72–2.58)</td>
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<table>
<thead>
<tr>
<th></th>
<th>Updated energy adjusted dietary glycemic index</th>
<th>Updated energy adjusted dietary glycemic load</th>
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<tr>
<td></td>
<td>Median</td>
<td>Median</td>
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<td>HRc (95% CI)</td>
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<tr>
<td>HRd (95% CI)</td>
<td>1 (Ref.)</td>
<td>1.27 (0.67–2.43)</td>
</tr>
</tbody>
</table>

**Table 2.** Hazard Ratios (95% CI) for total mortality by quartiles of energy adjusted dietary glycemic index and dietary glycemic load assessed at baseline in non-diabetic subjectsa.

*Abbreviations: Q, quartile; HR, hazard ratio; CI, confidence interval.

b Adjusted for sex, age (years), recruitment center, intervention group (Med Diet with EVOO, Med Diet with Nuts, Low fat diet).

c Adjusted for sex, age (years), recruitment center, intervention group (Med Diet + EVOO, Med Diet + Nuts, Low fat diet), smoking (never, past, current), education (low, middle, high, no data available), marital status (married, other), physical activity (continuous), BMI (continuous), self-reported history of cancer (yes, no), self-reported history of arterial hypertension (yes, no), total energy intake (continuous), alcohol intake (continuous) and dietary fiber intake (continuous, energy-adjusted).

d Multivariate model with additional adjustment for intake of saturated fatty acids (continuous, energy-adjusted) and monounsaturated fatty acids (continuous, energy-adjusted).

e Multivariate model with yearly updated measures of physical activity (continuous), BMI (continuous), total energy intake (continuous), alcohol intake (continuous), dietary fiber intake (continuous, energy-adjusted).

f Multivariate model with yearly updated measures with additional adjustment for saturated fatty acids intake (continuous, energy-adjusted) and monounsaturated fatty acids intake (continuous, energy-adjusted).

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Table 3. Sensitivity analysis. Hazard Ratios (95% CI) for total mortality according to baseline quartiles of energy adjusted dietary glycemic index and dietary glycemic load.

|                          | Energy limits percentiles 1 and 99 |                          |                          | Energy limits percentiles 5 and 95 |                          |                          | Sample with diabetic population |                          |                          | Excluding obese subjects (BMI≥30 kg/m²) |                          |                          | Including only obese subjects (BMI≥30 kg/m²) |                          |                          | Excluding subjects > 6 y of follow-up |                          |                          | Excluding subjects ≥75 y |                          |                          |
|--------------------------|-----------------------------------|--------------------------|--------------------------|-----------------------------------|--------------------------|--------------------------|---------------------------------|--------------------------|--------------------------|---------------------------------|--------------------------|--------------------------|---------------------------------|--------------------------|--------------------------|-------------------------------|--------------------------|--------------------------|-------------------------------|--------------------------|--------------------------|-------------------------------|--------------------------|--------------------------|
| n                        | Q3                                | Q4                       | p-trend                  | Q3                                | Q4                       | p-trend                  | Q3                                | Q4                       | p-trend                  | Q3                                | Q4                       | p-trend                  | Q3                                | Q4                       | p-trend                  | Excluding subjects ≥75 y | Q3                                | Q4                       | p-trend                  |
| Energy adjusted dietary glycemic index\(^b\) | 3606                              | 1.47 (0.80–2.71)         | 2.08 (1.12–3.87)         | 0.015                             | 1.14 (0.60–2.16)         | 2.10 (1.03–4.27)         | 0.042                             | Energy adjusted dietary glycemic load\(^b\) | 3333                              | 1.46 (0.76–2.80)         | 2.39 (1.23–4.63)         | 0.010                             | 0.86 (0.43–1.71)         | 1.96 (0.94–4.06)         | 0.109                             | Sample with diabetic population | 7013                              | 0.94 (0.68–1.30)         | 1.21 (0.86–1.71)         | 0.272                             | 1.02 (0.70–1.49)         | 1.16 (0.76–1.78)         | 0.657                             | Excluding obese subjects (BMI≥30 kg/m²) | 1888                              | 0.76 (0.35–1.65)         | 1.79 (0.83–3.86)         | 0.221                             | 0.79 (0.33–1.90)         | 1.94 (0.76–4.97)         | 0.214                             | Including only obese subjects (BMI≥30 kg/m²) | 1695                              | 3.75 (1.11–12.64)        | 3.24 (0.96–10.86)        | 0.044                             | 1.25 (0.46–3.42)         | 2.10 (0.69–6.38)         | 0.183                             | Excluding subjects > 6 y of follow-up | 2935                              | 1.13 (0.61–2.08)         | 1.66 (0.89–3.09)         | 0.052                             | 0.81 (0.42–1.56)         | 1.75 (0.88–3.45)         | 0.160                             | Excluding subjects ≥75 y | 3158                              | 1.46 (0.67–3.18)         | 2.35 (1.04–5.33)         | 0.026                             | 1.45 (0.66–3.19)         | 3.16 (1.32–7.54)         | 0.019                             |

\(^a\) Abbreviations: Q: quartile; HR: hazard ratio; CI: confidence interval; BMI: Body Mass Index.

\(^b\) Model adjusted for sex, age (years), recruitment center, intervention group (Med Diet + EVOO, Med Diet + Nuts, Low fat diet), smoking (never, past, current), education (low, middle, high, no data available), marital status (married, other), physical activity (continuous), BMI (continuous), self-reported history of cancer (yes, no), self-reported history of arterial hypertension (yes, no), total energy intake (continuous), alcohol (continuous), dietary fiber intake (continuous, energy-adjusted), saturated fatty acids intake (continuous, energy-adjusted) and monounsaturated fatty acids intake (continuous, energy-adjusted).

\(^c\) Dietary GI and GL quartiles were estimated for each specific population group.

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poor diet, physical inactivity, increased abdominal fat mass, and
decreased lean body mass contribute to the deterioration of
blood glucose metabolism [32]. Furthermore, this age-effect is similar
to previous findings, where the association between obesity and
mortality was attenuated with advancing age [33]. However the
age-related weaker associations may reflect confounding from
cohort variation in mortality risk, healthy participant effects (i.e.,
biases introduced by survey selection of healthy respondents) or
duration of exposure to the risk factor [34]. Therefore, we
consider that it can be not concluded whether dietary GI is
associated with higher risk of mortality in older subjects and
further studies with a larger sample size and follow-up are needed
to confirm the association between dietary GI and all-cause
mortality. Our results alternatively, may indicate that, in this
population at high cardiovascular risk, the quality of carbohydrates (represented by dietary GI) could be more important than its quantity (partially represented by dietary GL) in predicting all-
cause mortality [15].

We identified an association between the highest quartiles of
dietary GI and risk of all-cause mortality in obese subjects. Two
recent meta-analyses have shown that the effect of dietary GI on
the risk of coronary heart disease appeared more evident in
subjects with higher BMI, although the authors recommended
treating this information with caution because of the limited
evidence and diversity among the BMI cut-off points used across
studies [35,36]. Nevertheless, the individual response to a given
carbohydrate load is influenced by the degree of insulin resistance,
which is, firstly determined by the degree of adiposity, and also by
physical activity, genetics, and other aspects of diet. Thus, it might
be expected that the adverse metabolic effects of high-GI foods
would be exacerbated in sedentary, overweight, or genetically
susceptible persons [37].

Furthermore, higher values of dietary GI or GL could increase
the risk of all-cause mortality by raising the risk of chronic diseases.
Recent meta-analyses have shown a relationship between dietary GI,
GL and increased risk of CVD in women but not in men [35,38,39],
greater risk of T2DM [6,40,41], and risk for certain types of cancer
such as colorectal or endometrial ones [11,42]. Higher dietary GI has
also been associated with an increased risk of breast cancer
[6,11,43] although these results are contradictory [44–46].

After a high-GI meal, blood glucose concentration increases at
least twice that after a low-GI meal with the same nutrients and
energy. This hyperglycemia stimulates insulin release and inhibits
glucagon liberation. High insulin-to-glucagon ratio affects normal
anabolic responses such as uptake of nutrients by insulin-
responsive tissues, glycogenesis, lipogenesis, and inhibits gluco-
neogenesis and lipolysis. From 2 to 4 hours after a high-GI meal,
the absorption from the gastrointestinal tract declines, but the
effects of hyperinsulinemia and low glucagon remain. Blood
glucose drops to lower hypoglycemic range and release of free
fatty acid is more suppressed than compared with a low-GI meal.
In the late postprandial period, the low circulating concentration
of metabolic fuel activates the hormone response that restores
euglicemia and elevates free fatty acids to higher levels than
observed after low-GI meals [47].

Eventually these postprandial responses may contribute to insulin
resistance and obesity [48]. In a meta-analysis, Livesey et al. found that reduction in GL was associated with a decrease in
body weight and vice versa [49]. When comparing high GI foods,
such as white bread, Bautista-Castan˜o et al. found a dose-response
relationship between the increase in white bread consumption and
weight or waist circumference gain [50]. However, these results are
inconsistent. A systematic review of 14 randomized controlled trials
did not find differences in the effect of low GI/GL vs. high GI/GL
diets on anthropometric data, but decreases in C-reactive protein
and fasting insulin were significant in the low GI/GL groups [51].

Additionally, higher dietary GI has been associated with small
increases in C-reactive protein [52] which has been related to all-
cause mortality [53]. Another European study conducted in
overweight subjects, showed that following a low GI diet after a
weight loss intervention, had a greater decrease of high sensitivity
C-reactive protein blood levels than the high GI groups [54].
Moreover, in the PREDIMED study, top quartiles of dietary GI
were associated with higher plasma levels of TNF and IL-6 than
those in the lowest quartiles [55].

A study conducted in healthy elderly Europeans found that a
posteriori plant-based dietary pattern was associated with lower
all-cause mortality. This plant-based pattern with high intakes of
vegetables, vegetable oils, fruit, legumes and pasta/rice/other
gains and low intakes of potatoes, margarine and non-alcoholic
beverages, was correlated with the MeDiet pattern [56]. A
previous study has shown that greater adherence to the MeDiet is
inversely associated with dietary GI and GL [57]. A high degree
of adherence to the MeDiet has been associated with a reduction in
total mortality [58–62], obesity [63–65], T2DM [66,67], major
cardiovascular events [21,68] and their risk factors [23]. Thus,
Estruch et al. [23] assessed the effects of a 3-month intervention
with MeDiet on changes in cardiovascular risk factors within the
PREDIMED trial. MeDiet supplemented with EVOO, reduced
C-reactive protein levels. Moreover, other inflammation biomark-
ers such as interleukin-6, intercellular adhesion molecule-1
(ICAM-1) and vascular cell adhesion molecule-1 (VCAM-1)
decreased in subjects following a MeDiet supplemented either with
EVOO or nuts [23]. Even more, after one year of intervention with MeDiet, the prevalence of metabolic syndrome
was reduced by 13.7% when compared with control group [69].
However the number of randomized controlled-feeding trials that
compare low vs. high GI/GL diets and that include measures of
glucose homeostasis, blood lipids or inflammation is limited [70].

The limitations of this study are mainly methodological. Firstly,
due to the scarcity of GI values for Spanish foods, we used as
reference GI data from other countries. This fact could be a source
of bias, because GI values may differ wide ranges, depending on
variety, processing and cooking [71]. Secondly, the FFQ was not
designed to evaluate dietary GI and dietary GL. Thirdly, we
conducted the study in elderly subjects at high cardiovascular risk.
Therefore, our results cannot be generalized to other populations.
Finally, our study was conducted in a cohort that went through a
nutritional intervention, which may have had an effect on dietary
GI and GL. However, in order to address this issue, we adjusted
all analyses by intervention group to minimize the effect. Moreover,
because updated dietary information during the follow-up was used in our analyses, we accounted for changes in
dietary habits over time. To our knowledge, this is the first large
cohort study assessing GI and GL with yearly repeated measure-
ments of diet. Repeated measurements of diet capture changes in
dietary exposure, but also contribute to overcome, at least
partially, the potential problems of measurement errors in
nutritional epidemiology. Our study also has other strengths, such
as the large sample size that allowed us to adjust for all possible
potential confounders in the multivariate analyses. Other strengths
are the use of a comprehensive and validated FFQ and the
assignment of GI values trough an established protocol.

Conclusions

In summary, this study provides evidence that high GI diets are
related to increased risk of all-cause mortality in non-diabetic
elderly subjects at high cardiovascular risk. In the sensitivity analyses this association was statistically significant when subjects were younger than 75 years or obese. Nevertheless, more evidence is necessary to evaluate these associations in different population groups and further studies that elucidate the mechanisms supporting the inclusion of GI and GL in dietary recommendations.

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References


Author Contributions

Conceived and designed the experiments: LSM ICQ ASV MB MIC VRG MRC PBC EGG JL XP FA MF RMLR MAMG. Performed the experiments: ICQ AVS. Analyzed the data: ICQ ASV. Wrote the paper: ICQ AVS. Critical revision of the manuscript: RA MDRL MAMG. Primary responsibility for the final content: LSM. Provided input and feedback on manuscript: LSM ICQ ASV RE JSS DC HS JAP MDRL RA ER MB MIC VRG MRC PBC EGG JL XP FA MF RMLR MAMG. Read and approved the final version of the manuscript: LSM ICQ ASV RE JSS DC HS JAP MDRL RA ER MB MIC VRG MRC PBC EGG JL XP FA MF RMLR MAMG.

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