Glycemic index and glycemic load in relation to changes in body weight, body fat distribution, and body composition in adult Danes\(^1\)\(^-\)\(^3\)

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**ABSTRACT**

**Background:** A diet with a high glycemic index (GI) and glycemic load (GL) may promote overconsumption of energy and increase the risk of weight gain.

**Objective:** The objective of the study was to investigate the relation between GI and GL of habitual diets and subsequent 6-y changes in body weight, body fat distribution, and body composition in a random group of adult Danes.

**Design:** A prospective cohort study was conducted in a subsample of men and women from the Danish arm of the Monitoring Trends and Determinants in Cardiovascular Disease study. The subsample comprised 185 men and 191 women born in 1922, 1932, 1942, or 1952. A baseline health examination and a dietary history interview were carried out in 1987 and 1988; a follow-up health examination was performed in 1993 and 1994.

**Results:** Positive associations between GI and changes in body weight (ΔBW), percentage body fat (Δ%BF), and waist circumference (ΔWC) were observed in women after adjustment for covariates. Significant GI × sex × physical activity interactions for ΔBW, Δ%BF, and ΔWC were observed, and the associations in the sedentary women were particularly positive. No significant associations with GI were observed in men, and no significant associations with GL were observed in either sex.

**Conclusions:** High-GI diets may lead to increases in BW, body fat mass, and WC in women, especially in sedentary women, which suggests that physical activity may protect against diet-induced weight gain. No associations with GI were observed in men, which suggests sex differences in the association between GI and obesity development. *Am J Clin Nutr* 2006;84:871–9.

**KEY WORDS** Diet, carbohydrate, obesity, adults, prospective cohort study, sex differences, glycemic index, glycemic load

**INTRODUCTION**

The prevalence of obesity is rapidly increasing in the Western world. In 1999, 18% of the adult Danish population were obese [body mass index (BMI; in kg/m\(^2\)) ≥30] (1). Because of the adverse health effects of obesity, many attempts have been made to understand the main contributory causes. One theory states that a diet with a high glycemic index (GI) and glycemic load (GL) may contribute to the risk of weight gain (2–5) because such a diet can lead to hyperinsulinemia and insulin resistance (6) via increases in the blood glucose concentration (7). Those conditions contribute to greater carbohydrate oxidation, less fat oxidation, and, potentially, greater storage of energy in adipose tissue (2). The high insulin response causes large fluctuations in blood glucose, and, as a consequence, the feeling of hunger may return sooner than usual, leading to earlier initiation of the next meal. Theoretically, these effects on blood glucose may promote overconsumption of energy if the diet consists primarily of high-GI or -GL foods. However, previously published observational studies of the relation between GI or GL and different obesity measures are few; their results are inconsistent, and most of the studies have been cross-sectional (8–18).

In addition, intervention studies comparing the effects of ad libitum low-GI diets with high-GI or low-fat diets on subsequent changes in obesity measures have mostly been short-term studies, and the dietary effects have been modest (19–26). Furthermore, most of these studies were performed in subjects with obesity or diabetes rather than in normal-weight, healthy persons. Indeed, the response to differences in dietary GI or GL may vary between those with metabolic disturbances due to obesity or diabetes and the healthy population.

The aim of the current study therefore was to investigate the prospective relation between the GI and GL of the habitual diet and the subsequent 6-y changes in body weight (BW), body fat distribution, and body composition in a random subset of the adult Danish population.

**SUBJECTS AND METHODS**

**Subjects**

A random sample of adult Danes born in 1922, 1932, 1942, and 1952 was drawn from the Danish centralized civil registration...
system in 1982 and invited to participate in the Danish arm of the Monitoring Trends and Determinants in Cardiovascular Disease (MONICA) project, an international study conducted under the auspices of the World Health Organization. The sample comprised 4581 subjects. Of this group, 3608 (79%) participated in a baseline health examination in 1982. Those participants were all invited to return for another health examination between December 1987 and November 1988 (27). At the time of that examination, a dietary survey was performed in a subset of 552 subjects (27). A follow-up health examination was performed 6 y later (1993–1994). The subjects participating in both the dietary survey in 1987–1988 and the health examinations in 1987–1988 and 1993–1994 constituted the population sample for the current study.

All subjects gave written informed consent. The project was approved by the ethics committee for Copenhagen County and is in accordance with the Helsinki II Declaration.

Exclusion criteria

Subjects with missing data on BW, height, waist circumference (WC), hip circumference, body fat mass, or lean body mass in 1 of the 2 health examinations or with missing data on one or more of the covariates [ie, age, education, smoking habits, leisure-time physical activity (LTPA), and variables related to diet] were excluded. Subjects diagnosed with diabetes before 1987–1988 also were excluded.

Anthropometric data

All anthropometric measurements were conducted according to World Health Organization standards (28). BW was measured to the nearest 0.1 kg by using SECA weighing scales (Comaco A/S, Hemmel, Denmark). Height was measured to the nearest 0.1 cm. WC was measured horizontally midway between the lower rib margin and the iliac crest. Hip circumference was measured at the point of maximum circumference over the buttocks (29). Bioelectrical impedance analysis (BIA-103 RJL-system-analyzer; RJL, Detroit, MI) was used to measure body composition. Measurements were obtained by using tetra-polar electrode placement on the right hand and foot (30). Estimation of body fat was made by using an algorithm previously developed in a subgroup from the same overall sample of Danes (29):  

\[
BF (kg) = 0.819 \times BW (kg) - 0.279 \times Ht^2/R (cm^2/ohm) \\
- 0.064 \times sex \times BW (kg) + 0.077 \times age (y) \\
- 0.231 \times Ht (cm) + 14.941 (I)
\]

where BF is body fat, and Ht is height. Sex is coded as 1 for men and 0 for women. Fat-free mass was estimated as the difference between BW and body fat mass estimated from the bioelectrical impedance analysis.

Questionnaire information

Queries about LTPA covered activities in the following categories: 1) mostly sitting, 2) light activity for ≥4 h/wk, 3) active in sports for ≥3 h/wk or heavy work during leisure, and 4) active in competitive sports several times a week (31). The subjects who were sedentary made up group 1, and the subjects who were active made up groups 2, 3, and 4. Questions about smoking habits were used to assess whether a person was a never smoker, former smoker, light smoker (0–14 g tobacco/d), medium smoker (15–24 g tobacco/d), or heavy smoker (≥25 g tobacco/d). Nonsmokers made up smoking status groups 1 and 2; smokers made up smoking status groups 3, 4, and 5. Questions about education divided the participants into 3 education groups, with ≤7, 8–11, or ≥12 y in school, respectively.

Diet

Information on diet was collected by using a dietary history interview. A Registered Dietitian performed all interviews using a detailed, coded interview form. Average daily intake was based on intakes during the previous month. Amounts eaten were assessed by using models, series of photographs, and household measures (32). Intakes of nutrients were estimated by using DANKOST software (version 2.0; Dans Catering Center, Herlev, Denmark), which is based on the Danish food-composition tables (33).

Assessment of glycemic index and glycemic load

A weighted GI and overall GL were assigned to the diet of the participants with the use of values from the 2002 international table of GI and GL values (34). Precise GI values may vary because of differences in methods, intrasubject variations, and processing and cooking of the food (34–36). To minimize such variations, the GI values used to calculate weighted GI and overall GL in the current study were calculated on the basis of means of GI values from different studies measuring the GI of similar foods. Four criteria were used to select the GI values used for the calculation of mean GI values from the GI table (34). One, the GI value was measured over a 2-h period if subjects were healthy or over a 3-h period if subjects had type 1 or type 2 diabetes (7, 35, 36). Two, the reference food originally used to measure the GI value was either glucose or white bread (when glucose was the reference food, the GI value was multiplied by 1.43 to standardize the GI value to the white bread reference). Three, the reference food and test food portions used for measurement both contained (with few exceptions) 50 g available carbohydrate (7). Four, the GI value was (with few exceptions) measured for ≥6 subjects (37). Only root vegetables and legumes were included in the calculations of weighted GI and overall GL; the GI values of other vegetables have not been measured. However, most of the vegetables not included in the calculations contain an amount of carbohydrates too small to affect the measures appreciably, regardless of whether they have high or low GI (38).

Weighted GI was calculated by using the following formula (39):

\[
\text{Weighted GI} = \sum A_i \times CHO_i \times GI_i \times \sum A_i \times CHO_i
\]

where \( A_i \) is the amount of the food (i) in g/d; \( CHO_i \) is the amount of available carbohydrate per g food; and \( GI_i \) is the GI value for the food. The numerator is the overall GL, and the denominator is the total intake of available carbohydrate (39). GI is expressed with white bread as the reference food.

Statistical analyses

Differences between participants who were excluded and those who were included in the analyses were examined by using analysis of variance. Most differences between excluded and included participants were related to age differences. Tests for
trend were performed by using sex stratification for all variables and one-factor analysis of variance with quintile medians for GI and GL, respectively, as independent variables.

Multiple linear regression analysis was used to examine associations between the exposure variables GI and GL and the outcome variables change in BW, change in %BF, change in WC, and change in hip circumference. Confounders were chosen a priori. Analyses with GI as exposure variable were adjusted for baseline BW, %BF, WC, and hip circumference; significantly lower intake of energy from protein, lower dietary fiber intake, and higher intakes of energy from fat and added sugar than did subjects with lower dietary GI. A GI quintile also had significantly lower intake of energy from protein, lower dietary fiber intake, and higher intakes of energy from fat and added sugar than did subjects with lower dietary GI. A GI quintile was present for these variables (Table 2).

Descriptive results

Dietary GI and GL were calculated with the use of white bread as the reference food. Subjects with high dietary GI had significantly lower intake of energy from protein, lower dietary fiber intake, and higher intakes of energy from fat and added sugar than did subjects with lower dietary GI. A GI quintile × sex interaction was present for baseline hip circumference; however, there was no trend across quintiles of GI for either men or women. Significant differences between the sexes were present for baseline values of BW, %BF, WC, intake of energy from carbohydrate, and total energy intake. However, no trends across GI quintiles were present for these variables (Table 2).

Subjects consuming a high-GI diet had significantly lower baseline BW, %BF, WC, and hip circumference; significantly lower intake of fat; and significantly higher intakes of carbohydrate, total energy, added sugar, and dietary fiber than did subjects consuming low-GI diets. GL quintile × sex interactions were present for intake of energy from protein and educational level. Both men and women had decreasing protein intakes across increasing quintiles of GL. Only in women did the percentage with a low level of education change significantly (ie, it decreased) across increasing quintiles of GL (Table 2). No trends were observed across quintiles of either GI or GL for changes in

TABLE 1
Selected baseline characteristics of participants

|                  | Men                          | Women                        | Sex | P
|------------------|------------------------------|------------------------------|-----|-----
|                  | Sedentary (n = 42)           | Active (n = 143)             |      |     |
| Dietary glycemic index\(^1\) | 81.8 ± 4.6\(^1\)           | 81.7 ± 5.2                   |      |     |
| Dietary glycemic load\(^2\)    | 158 ± 56                    | 169 ± 66                     |      |     |
| Body weight (kg)               | 81.4 ± 11.8                 | 78.2 ± 11.9                  |      |     |
| Percentage body fat (%)        | 25.3 ± 5.4                  | 22.5 ± 6.0                   |      |     |
| Waist circumference (cm)       | 93.2 ± 10.4                 | 89.7 ± 9.8                   |      |     |
| Hip circumference (cm)         | 98.9 ± 5.6                  | 98.0 ± 6.1                   |      |     |
| Age (y)                       | 48.3 ± 9.8                  | 49.7 ± 10.9                  |      |     |
| Protein intake (% of energy)   | 14.0 ± 2.2                  | 14.1 ± 2.4                   |      |     |
| Fat intake (% of energy)       | 41.3 ± 5.5                  | 40.0 ± 5.8                   |      |     |
| Carbohydrate intake (% of energy) | 38.0 ± 7.4             | 39.6 ± 6.7                   |      |     |
| Alcohol intake (% of energy)   | 6.7 ± 6.1                   | 6.3 ± 6.4                    |      |     |
| Energy intake (MJ)             | 101.2 ± 2.4                 | 104.3 ± 3.2                  |      |     |
| Added sugar intake (g)         | 33.1 ± 27.5                 | 35.9 ± 33.9                  |      |     |
| Dietary fiber intake (g)       | 23.3 ± 8.5                  | 25.3 ± 10.0                  |      |     |

\(^1\) LTPA, leisure-time physical activity. No significant sex × LTPA interactions were observed (ANOVA with each baseline variable as a dependent variable). In reduced models, main effects of sex and LTPA were examined.  
\(^2\) Dietary glycemic index and load were calculated with white bread as the reference food.  
\(^3\) ± SD (all such values).
TABLE 2
Distribution of baseline variables by quintile (Q) of dietary glycemic index (GI) and of dietary glycemic load (GL) in 376 Danish men and women

<table>
<thead>
<tr>
<th></th>
<th>Men (n = 185)</th>
<th>Women (n = 191)</th>
<th>Quintile × sex interaction</th>
<th>Sex</th>
<th>GI quintile</th>
<th>GL quintile</th>
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<tbody>
<tr>
<td>n</td>
<td>37</td>
<td>37</td>
<td>37</td>
<td>37</td>
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<td>—</td>
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<td>Dietary GI</td>
<td></td>
<td></td>
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<td>—</td>
</tr>
<tr>
<td>Median</td>
<td>74.3</td>
<td>79.7</td>
<td>82.1</td>
<td>84.6</td>
<td>87.4</td>
<td>—</td>
</tr>
<tr>
<td>± SD</td>
<td>74.2 ± 2.7</td>
<td>79.6 ± 0.9</td>
<td>82.0 ± 0.6</td>
<td>84.6 ± 0.8</td>
<td>88.3 ± 2.4</td>
<td>—</td>
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<td>Baseline values</td>
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<td></td>
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<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>80.4 ± 13.3</td>
<td>80.9 ± 12.3</td>
<td>78.7 ± 14.2</td>
<td>77.7 ± 9.7</td>
<td>76.9 ± 10.9</td>
<td>0.15 &lt; 0.0001</td>
</tr>
<tr>
<td>Percentage body fat (%)</td>
<td>22.9 ± 5.4</td>
<td>23.6 ± 5.5</td>
<td>23.4 ± 5.3</td>
<td>22.9 ± 7.4</td>
<td>21.6 ± 10.0</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>91.2 ± 9.4</td>
<td>91.5 ± 9.9</td>
<td>90.7 ± 10.8</td>
<td>90.5 ± 8.8</td>
<td>89.7 ± 11.3</td>
<td>0.36 &lt; 0.0001</td>
</tr>
<tr>
<td>Hip circumference (cm)</td>
<td>99.1 ± 6.3</td>
<td>99.3 ± 5.7</td>
<td>97.7 ± 6.6</td>
<td>97.5 ± 5.2</td>
<td>97.4 ± 6.3</td>
<td>0.05 — 0.13 (M)</td>
</tr>
<tr>
<td>Age (y)</td>
<td>46.4 ± 9.8</td>
<td>48.5 ± 11.4</td>
<td>48.8 ± 10.9</td>
<td>52.8 ± 10.0</td>
<td>50.4 ± 10.7</td>
<td>0.08 0.76</td>
</tr>
<tr>
<td>Protein intake (% of energy)</td>
<td>15.4 ± 2.8</td>
<td>16.4 ± 2.4</td>
<td>14.0 ± 2.2</td>
<td>13.1 ± 1.7</td>
<td>13.3 ± 1.8</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Fat intake (% of energy)</td>
<td>38.1 ± 5.1</td>
<td>40.1 ± 6.8</td>
<td>39.4 ± 5.4</td>
<td>41.2 ± 5.4</td>
<td>42.6 ± 4.9</td>
<td>0.42 &lt; 0.0006</td>
</tr>
<tr>
<td>Carbohydrate intake (% of energy)</td>
<td>38.6 ± 6.9</td>
<td>40.6 ± 8.2</td>
<td>41.4 ± 7.3</td>
<td>37.1 ± 5.2</td>
<td>38.4 ± 5.9</td>
<td>&lt; 0.0001 0.22</td>
</tr>
<tr>
<td>Energy intake (MJ)</td>
<td>10.6 ± 3.7</td>
<td>10.1 ± 3.1</td>
<td>10.4 ± 2.5</td>
<td>10.8 ± 3.0</td>
<td>9.8 ± 2.6</td>
<td>0.43 &lt; 0.0001</td>
</tr>
<tr>
<td>Added sugar intake (g)</td>
<td>25.1 ± 27.2</td>
<td>34.5 ± 36.5</td>
<td>37.8 ± 31.8</td>
<td>33.5 ± 24.7</td>
<td>42.5 ± 38.8</td>
<td>0.43 &lt; 0.0001</td>
</tr>
<tr>
<td>Dietary fiber intake (g)</td>
<td>25.1 ± 8.7</td>
<td>26.2 ± 11.0</td>
<td>26.7 ± 11.9</td>
<td>24.7 ± 7.8</td>
<td>21.6 ± 8.0</td>
<td>0.43 &lt; 0.0001</td>
</tr>
<tr>
<td>Nonsmokers (%)</td>
<td>46</td>
<td>59</td>
<td>54</td>
<td>49</td>
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<td>56</td>
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<tr>
<td>Sedentary (%)</td>
<td>19</td>
<td>24</td>
<td>27</td>
<td>27</td>
<td>16</td>
<td>21</td>
</tr>
<tr>
<td>Education 0–7 y (%)</td>
<td>24</td>
<td>30</td>
<td>19</td>
<td>30</td>
<td>41</td>
<td>31</td>
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<tr>
<td>Dietary GL</td>
<td></td>
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<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Median</td>
<td>93</td>
<td>126</td>
<td>159</td>
<td>186</td>
<td>250</td>
<td>79</td>
</tr>
<tr>
<td>± SD</td>
<td>91 ± 15</td>
<td>128 ± 10</td>
<td>159 ± 8</td>
<td>188 ± 10</td>
<td>265 ± 51</td>
<td>179 ± 5</td>
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<tr>
<td>Baseline values</td>
<td></td>
<td></td>
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<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>84.2 ± 11.6</td>
<td>77.8 ± 10.2</td>
<td>79.9 ± 13.8</td>
<td>76.4 ± 11.6</td>
<td>73.6 ± 10.7</td>
<td>0.50 &lt; 0.0001</td>
</tr>
<tr>
<td>Percentage body fat (%)</td>
<td>26.8 ± 4.4</td>
<td>23.1 ± 4.8</td>
<td>25.0 ± 5.6</td>
<td>21.5 ± 6.6</td>
<td>20.6 ± 6.6</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>98.1 ± 6.2</td>
<td>90.0 ± 8.9</td>
<td>91.4 ± 10.1</td>
<td>87.2 ± 9.3</td>
<td>87.5 ± 10.9</td>
<td>0.30 &lt; 0.0003</td>
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<tr>
<td>Hip circumference (cm)</td>
<td>101.6 ± 5.2</td>
<td>97.8 ± 5.6</td>
<td>98.6 ± 6.7</td>
<td>96.3 ± 5.5</td>
<td>96.3 ± 5.6</td>
<td>0.07 &lt; 0.0003</td>
</tr>
<tr>
<td>Age (y)</td>
<td>50.7 ± 9.6</td>
<td>48.2 ± 9.7</td>
<td>50.1 ± 11.5</td>
<td>47.4 ± 10.7</td>
<td>50.6 ± 10.2</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Protein intake (% of energy)</td>
<td>15.3 ± 2.7</td>
<td>14.5 ± 2.5</td>
<td>14.3 ± 2.0</td>
<td>13.7 ± 2.0</td>
<td>12.6 ± 1.6</td>
<td>— 0.0002</td>
</tr>
<tr>
<td>Fat intake (% of energy)</td>
<td>41.2 ± 4.7</td>
<td>40.9 ± 6.4</td>
<td>41.0 ± 6.6</td>
<td>39.5 ± 6.0</td>
<td>38.8 ± 4.8</td>
<td>0.10 &lt; 0.02</td>
</tr>
<tr>
<td>Carbohydrate intake (% of energy)</td>
<td>33.4 ± 5.2</td>
<td>37.7 ± 6.7</td>
<td>38.3 ± 6.1</td>
<td>40.7 ± 4.4</td>
<td>45.9 ± 5.2</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Energy intake (MJ)</td>
<td>7.5 ± 19</td>
<td>8.0 ± 2.0</td>
<td>10.6 ± 2.2</td>
<td>11.3 ± 2.2</td>
<td>13.4 ± 2.7</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Added sugar intake (g)</td>
<td>10.9 ± 8.4</td>
<td>22.4 ± 13.7</td>
<td>28.6 ± 16.3</td>
<td>39.3 ± 26.2</td>
<td>75.0 ± 40.5</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Dietary fiber intake (g)</td>
<td>16.0 ± 4.5</td>
<td>20.6 ± 5.1</td>
<td>25.3 ± 7.2</td>
<td>27.3 ± 6.4</td>
<td>31.1 ± 11.3</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Nonsmokers (%)</td>
<td>51</td>
<td>38</td>
<td>51</td>
<td>59</td>
<td>54</td>
<td>56</td>
</tr>
<tr>
<td>Sedentary (%)</td>
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<td>16</td>
<td>35</td>
<td>19</td>
<td>19</td>
<td>23</td>
</tr>
<tr>
<td>Education 0–7 y (%)</td>
<td>22</td>
<td>24</td>
<td>32</td>
<td>38</td>
<td>27</td>
<td>46</td>
</tr>
</tbody>
</table>

1 Dietary GI and GL were calculated with white bread as the reference food. Sex × GI or GL (in quintiles) interactions were tested with ANOVA with each baseline variable as the dependent variable. If sex × GI or GL interaction was present, trend analysis across quintiles of GI or GL was performed separately for men and women. If no interaction was present, main effects of sex and GI or GL quintiles were examined in reduced models.

2 ± SD (all such values).
GLYCEMIC INDEX AND LOAD IN RELATION TO OBESITY

TABLE 3
Distribution of outcome variables according to quintiles (Q) of dietary glycemic index (GI) and dietary glycemic load (GL) in 376 Danish men and women.

<table>
<thead>
<tr>
<th>Dietary GI</th>
<th>Men (n = 185)</th>
<th>Women (n = 191)</th>
<th>P</th>
<th>F for trend</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
</tr>
<tr>
<td>Dietary GI</td>
<td>n</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>1.9 ± 5.7.a</td>
<td>2.9 ± 5.8</td>
<td>1.8 ± 3.5</td>
<td>1.9 ± 3.8</td>
</tr>
<tr>
<td>Percentage body fat (% points)</td>
<td>2.1 ± 3.4</td>
<td>2.2 ± 3.2</td>
<td>2.4 ± 2.4</td>
<td>2.5 ± 2.2</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>1.5 ± 5.9</td>
<td>2.1 ± 4.8</td>
<td>2.3 ± 4.5</td>
<td>2.7 ± 4.7</td>
</tr>
<tr>
<td>Hip circumference (cm)</td>
<td>0.7 ± 3.3</td>
<td>1.3 ± 3.6</td>
<td>0.4 ± 2.5</td>
<td>0.8 ± 2.4</td>
</tr>
</tbody>
</table>

1 Sex × GI or GL (in quintiles) interactions were tested with ANOVA with each outcome variable as the dependent variable. No sex × GI or GL quintile interactions were observed. In reduced models, main effects of sex and GI or GL quintiles were examined.

2 SD (all such values).

BW, %BF, WC, or hip circumference. Distributions of the outcome variables according to quintiles of GI and GL are shown in Table 3.

Glycemic index

The GI was not significantly associated with change in any of the obesity measures in men. This was observed in both the crude and adjusted analyses (Table 4). In the crude analyses, GI also was not significantly associated with changes in any of the obesity measures in women. In the adjusted analyses, GI was positively associated with changes in BW (P = 0.04) and %BF (P = 0.04). In addition, a borderline significant positive association was seen between GI and change in WC (P = 0.07; Table 4). In 6 y, values per 10-unit increase in baseline GI rose by 2% (95% CI: 0.1, 4%) for BW [equal to a gain of 3.8 kg in a woman with median BW (ie, 62.8 kg) at baseline], 3 percentage points (95% CI: 1, 4 percentage point; P = 0.002) for %BF, and by 2 cm (95% CI: −0.1, 3 cm) for WC.

Significant GI × sex × LTPA interactions were observed for changes in BW (Figure 1), %BF (Figure 2), and WC (Figure 3). The associations between GI and changes in the obesity measures in the interaction models were evident only in the sedentary women. In 6 y, values per 10-unit increase in baseline GI rose in sedentary women by 6% (95% CI: 2, 9%; P = 0.001) for BW [equal to a gain of 3.8 kg in a woman with median BW (ie, 62.8 kg) at baseline], 3 percentage points (95% CI: 1, 4 percentage point; P = 0.002) for %BF, and 4 cm (95% CI: 1, 7 cm; P = 0.008) for WC. In active women and all men, the associations between GI and changes in body weight, %BF, and WC in the interaction models were not significant. No significant interactions were observed for change in hip circumference (data not shown).

Glycemic load

GL was not significantly associated with any of the outcome variables in men. In women, there was a borderline significant

TABLE 4
Associations between baseline dietary glycemic index (GI) and 6-y changes in body weight, percentage body fat, and waist and hip circumferences in 376 Danish men and women.

<table>
<thead>
<tr>
<th>6-y Change</th>
<th>Men (n = 185)</th>
<th>Women (n = 191)</th>
<th>Adjusted analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crude analyses</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Men (n = 185)</td>
<td>Women (n = 191)</td>
<td></td>
</tr>
<tr>
<td>log (Body weight)</td>
<td>−0.0004 (−0.002, 0.001)</td>
<td>0.001 (−0.0009, 0.003)</td>
<td>−0.0002 (−0.002, 0.002)</td>
</tr>
<tr>
<td>Percentage body fat (% points)</td>
<td>0.02 (−0.05, 0.10)</td>
<td>0.04 (−0.04, 0.13)</td>
<td>0.02 (−0.07, 0.11)</td>
</tr>
<tr>
<td>Waist circumference</td>
<td>0.02 (−0.12, 0.16)</td>
<td>0.09 (−0.08, 0.26)</td>
<td>0.02 (−0.14, 0.17)</td>
</tr>
<tr>
<td>Hip circumference</td>
<td>0.004 (−0.09, 0.09)</td>
<td>0.05 (−0.09, 0.18)</td>
<td>−0.003 (−0.10, 0.10)</td>
</tr>
</tbody>
</table>

1 All values are β regression coefficient; 95% CI in parentheses. Dietary GI was calculated with white bread as the reference food. All analyses were performed by using multiple linear regression analysis with stratification by sex. No sex × GI interaction was present.

2 Adjusted for baseline value of outcome variable.

3 Adjusted for baseline body weight, age, smoking status (smoker or nonsmoker), years of education (≤7, 8–11, or ≥12 y), leisure-time physical activity (sedentary or active), energy intake (kJ), percentage of energy from fat and protein, and fiber intake (g).

4 P < 0.05.

5 Adjusted for baseline percentage body fat, age, smoking status, years of education, leisure-time physical activity, energy intake (kJ), percentage of energy from fat and protein, and fiber intake (g).

6 Adjusted for baseline waist circumference, hip circumference, body weight, age, smoking status, years of education, leisure-time physical activity, energy intake (kJ), percentage of energy from fat and protein, and fiber intake (g).

7 P = 0.07.
inverse association between GL and changes in WC in the adjusted analysis ($P = 0.06$). The change in WC was $-0.5$ cm (95% CI: $-1.0, 0.01$ cm) for a 10% increase in baseline GL. There were no other significant associations between obesity measures and GL for women (data not shown). We evaluated whether the association between GL and changes in the obesity measures was modified by sex and LTPA in the same way that we conducted the GI analyses, but none of the 3-way interaction terms were significant (data not shown).

To our knowledge, the current study is the first long-term prospective study to examine relations between GI and GL and the subsequent changes in BW, body composition, or body fat distribution. Recently, Ma et al (18) examined relations between dietary GI and BMI and observed that the 1-y change in daily dietary GI was positively associated with the simultaneous 1-y change in BMI in a sample of 20–70-y-old men and women. These findings are consistent with the findings of the current study. In line with this, some long-term intervention (24, 26) and animal (41, 42) studies observed positive associations between dietary GI and changes in obesity measures. However, other long-term intervention studies did not find such associations (23, 25). In the current study, baseline GI was associated with increases in BW, %BF, and WC in women after adjustment for confounding factors; however, associations in men were not significant.

We decided to perform the analyses separately in men and women, even though no exposure variables $\times$ sex interactions were present. This was an a priori decision based on previous research that showed biologically determined sex differences in body composition and fat distribution (43). We did observe associations between GI and some of the outcome measures in women, but no tendencies toward significant associations were observed in men (Table 4). A reason for the lack of interactions between the exposure variables and sex, despite these different results, may be lack of power: we had complete information on only 376 subjects.

Associations between GI and changes in BW, %BF, and WC were significantly stronger in the sedentary than in the active women. These findings are in line with the observations of Stubbs et al (44), who reported that the ability to regulate energy intake in proportion to energy expenditure seemed poorer in sedentary than in active subjects, and of Lissner et al (45), who found that, compared with active women, sedentary women had
a higher sensitivity toward effects of diet intake on weight development. Accordingly, the inactive subgroup in this study seemed more susceptible than the active subgroup to the proposed negative effects of a high-GI diet on the development of obesity that is potentially mediated by a higher degree of insulin resistance (46), by influences of physical activity on appetite and energy balance regulation (3), or by a direct protection against diet-induced changes in BW and body composition in the physically active.

GI was not associated with changes in hip circumference in women or men, potentially because the variation in change in hip circumference generally is smaller than the variation in change in waist circumference (47). In addition, the effect of GI on changes in obesity measures did not differ between age groups in the current study.

The question remains: why are sedentary women but not sedentary men sensitive to the negative effects of a high-GI diet on BW and obesity development? An earlier study suggested that the genetic regulation of weight development may be differentially modified by physical activity in men and women (48), so that a sedentary lifestyle seems to promote the development of obesity in genetically predisposed men but not in genetically predisposed women. Hence, the genetic influence may partly explain why we did not find any associations between diet and obesity measures in men, whereas lifestyle factors other than physical activity, such as diet, may be responsible for changes in BW in women. In other words, genetic factors may have overruled the effects of diet on development of obesity in men, whereas in women effects of diet may have overruled the weak influence of the genetic factors. This is also supported by studies of dietary GI and risk of type 2 diabetes suggesting that men (13) may be less susceptible than are women to the proposed adverse effects of a high dietary GI on the risk of type 2 diabetes (12).

The associations observed in sedentary women were quite strong. A 10-unit difference in weighted GI in this group was associated with a 3.8-kg difference in body weight gain, a 3-percentage point difference in body fat gain, and a 4-cm difference in the increase in WC. Sedentary women therefore may particularly benefit from reducing the weighted GI of their diet.

The inverse associations observed between GL and baseline obesity measures may be a consequence of the nature of GL, which reflects both the quality and quantity of carbohydrate in the diet. A high-GL diet, therefore, may be a generally more healthy diet, with a higher carbohydrate and lower fat content than a low-GL diet. This paradox may in part explain the inverse associations observed. Furthermore, the international dietary guidelines essentially recommend a high-GL diet (49), and the people who follow those dietary recommendations may be generally more health-conscious than are those who do not follow the recommendations. This dynamic may also have contributed to the observation of inverse associations. However, none of the associations between GL and changes in obesity measures were significant, even if the observed borderline significant association between GL and changes in WC in women would suggest that a high-GL diet may protect against abdominal obesity development in women. The change in WC with a 10% increase in GL was negligible and not of clinical relevance, and the association was probably due to chance. The lack of consistency between the GI and GL analyses may have been due in part to an influence of carbohydrate intake on the associations between GI and changes in obesity measures. However, adjustment for carbohydrate intake in the GI analyses did not change the estimates, and carbohydrate intake had no independent predictive power in the analyses in either men or women. Hence, differences in carbohydrate intake do not seem to explain, in the current study, why GI but not GL predicts weight change.

Several limitations should be noted. First, we had only one measure of diet (at baseline), and the current analyses assume that this dietary assessment describes the habitual diet of the participants and that the diet does not change considerably during the follow-up period. However, because of the prospective nature of the study, a potential bias in diet reporting should be independent of the subsequent weight status. Furthermore, a random bias potentially introduced by misclassification would tend to dilute or even hide true associations. The observed associations in women may therefore be expected to be conservative estimates of the “true” associations.

Second, it can be argued that the impedance method is not valid for detecting small changes in body composition. However, this method has been found valid in several studies (50), particularly when population-specific algorithms for calculating body fat were applied (29), as they were in the current study. Third, physical activity was assessed by using a questionnaire. There was, therefore, a potential risk that some persons were misclassified because the questionnaire may have been too crude to distinguish between less and more active persons. Others have, however, found that this questionnaire provides a valid assessment of physical activity level (51).

Fourth, the calculation of the GI of the habitual diet was made by using values from the GI tables of Foster-Powell et al (34). These values are mainly from the United States, Canada, and Australia, and they potentially made the calculation of GI in this group of Danish men and women less accurate. In an attempt to overcome these inaccuracies, we decided to use average values calculated from similar food items that fulfilled certain criteria (see Subjects and Methods). In this way, error due to misclassification of food items was minimized along with the reduction in the risk of assigning a food a GI value far from the true value. Still, there are other factors, such as the effect of mixed meals (52), macronutrient composition (53), “second-meal effect” (54), and other food characteristics that may affect the GI of the diet. These factors are difficult to assess or take into account, because they are related to other characteristics of the diet. Therefore, the calculated GI of the diet should probably be viewed as describing the glycemic potential of the diet, rather than as describing the physiologic glycemic response expected from the particular diet. It is possible that both known and unknown modifying factors have a significant influence on the short-term effects of diets or meals with a particular GI, which would make it extremely difficult to ascertain the true short-term physiologic effects. The random effects of modifying factors may influence the longer-term effects less, thereby making the GI more reliable in longer-term studies. Positive effects of diets based on foods with low-GI table values have been observed on energy balance (24), glycemic control (55), insulin sensitivity (20), cardiovascular disease (17), and so on. Therefore, it seems likely that foods with low-GI table values indeed do have positive effects on metabolism, including weight changes. Taken together, results from the current study and previous studies would suggest that habitually consuming a low-GI diet may protect against obesity development, at least in women.
It may, however, also be necessary to define other aspects of
the diet apart from GI—eg, low fat and sugar intakes and a high
intake of dietary fiber—to see these positive effects. The men-
tioned aspects will most often be a natural consequence of
choosing low-GI foods, but it is indeed possible to eat a low-GI diet that
is rich in sugar and fat and low in dietary fiber (21).

In conclusion, our results indicate that a low-GI diet may
protect against increases in BW and general and abdominal obe-
sity in women—especially in those who are sedentary—which
suggests that physical activity may offer protection against diet-
induced weight gain and obesity. We observed no effect of GI in
men, which suggests possible sex differences. More longitudi-
nal, observational studies and primary prevention intervention
studies in normal-weight subjects are needed to ascertain
whether the GI and GL of the habitual diet affect natural body
weight and obesity development during life.

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harmonization, and obtaining funding. HH-B, BLH, and AF were responsible
for the analysis and interpretation of the data. HH-B was responsible for
drafting the manuscript, and HH-B, BLH, and AF edited the manuscript
and produced the final version. None of the authors had a personal or financial
conflict of interest.

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