Increasing the Percentage of Energy from Dietary Sugar, Fats, and Alcohol in Adults Is Associated with Increased Energy Intake but Has Minimal Association with Biomarkers of Cardiovascular Risk

Gregory L. Austin and Patrick M. Krueger

Abstract

The optimal diet composition to prevent obesity and its complications is unknown. Study aims were to determine the association of diet composition with energy intake, homeostatic model assessment–insulin resistance (HOMA-IR), and C-reactive protein (CRP). Data were from the NHANES for eligible adults aged 20–74 y from 2005 to 2006 (n = 3073). Energy intake and diet composition were obtained by dietary recall. HOMA-IR was calculated from fasting insulin and glucose concentrations, and CRP was measured directly. Changes for a 1-point increase in percentage of sugar, saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs), polyunsaturated fatty acids (PUFAs), and alcohol were determined across their means in exchange for a 1-point decrease in percentage of nonsugar carbohydrates. Regression analyses were performed, and means ± SEs were estimated. Increasing the percentage of sugar was associated with increased energy intake in men (23 ± 5 kcal; P < 0.001) and women (12 ± 3 kcal; P = 0.002). In men, increasing percentages of SFAs (58 ± 13 kcal; P = 0.001) and PUFAs (66 ± 19 kcal; P < 0.001) were associated with increased energy intake. In women, increasing percentages of SFAs (27 ± 10 kcal; P = 0.02), PUFAs (43 ± 6 kcal; P < 0.001), and MUFAs (36 ± 13 kcal; P = 0.01) were associated with increased energy intake. Increasing the percentage of alcohol was associated with increased energy intake in men (38 ± 7 kcal; P < 0.001) and women (25 ± 8 kcal; P = 0.001). Obesity was associated with increased HOMA-IR and CRP in both genders (all P < 0.001). Increasing PUFAs was associated with decreasing CRP in men (P = 0.02). In conclusion, increasing the percentage of calories from sugar, fats, and alcohol was associated with substantially increased energy intake but had minimal association with HOMA-IR and CRP.

Introduction

The prevalence of obesity has increased substantially since the 1970s (1,2). According to the NHANES, obesity among adults aged 20–74 y increased from 11.9% in men and 16.6% in women in NHANES I (1971–1975) to 35.5% in men and 36.3% in women in NHANES 2009–2010. Obesity results when energy intake exceeds energy expenditure over time. Holding energy expenditure constant, higher energy intake would be expected to lead to weight gain. The energy content of food is derived from macronutrients (carbohydrate, fat, protein, and alcohol). We previously demonstrated that an increased percentage of calories from fat and carbohydrate is associated with increased energy intake (3). Differences between sugar and nonsugar carbohydrates on energy intake remain unclear. Similarly, differences between SFAs, MUFAs, and PUFAs on energy intake are also unclear, as is the effect of alcohol. Diabetes and cardiovascular disease have increased in parallel with the increase in obesity. These disorders increase patient morbidity, mortality, and health care costs (4). Obese individuals are more likely to develop insulin resistance (a precursor to diabetes) and have higher concentrations of circulating C-reactive protein (CRP) (5), a risk factor for cardiovascular disease (6). The effect of diet composition on these biomarkers is controversial. Some weight-loss trials assessed the effect of the macronutrient composition of a weight-loss diet on CRP and insulin resistance (7,8). However, many of these studies were confounded by weight loss, and many participants did not maintain the diet used to achieve weight loss and returned to
eating a more balanced diet at the time biomarkers were reassessed.

The purpose of this study was to evaluate the association of diet composition with energy intake, insulin resistance, and CRP in a representative sample of individuals who were not on a diet for weight loss or other health-related reasons. Our hypothesis is that diet composition is associated with energy intake, and that increased energy intake predisposes to weight gain and the development of obesity. In turn, obesity is the primary risk factor for insulin resistance and an elevated CRP. Identifying an optimal macronutrient composition to minimize energy intake and to optimize biomarkers may provide evidence for dietary recommendations to treat obesity and reduce its complications.

Methods

Population. Our data are from the NHANES. The NHANES is a complex multistage probability sample of the United States civilian, noninstitutionalized population designed to assess the health and nutritional status of adults and children in the US (9). We used data on 4381 adults aged 20–74 y in the 2005–2006 NHANES wave to determine the association of sugar, different dietary fats, and alcohol with energy intake, insulin resistance, and CRP; 3073 individuals who met inclusion criteria were included in the final analyses. Interviews and physical examinations were used to collect demographic, socioeconomic, dietary, and laboratory data. Height and weight were measured by using standardized protocols and calibrated equipment, and BMI was calculated as kg/m^2. Blood samples were obtained to measure serum CRP, fasting insulin, and fasting glucose concentrations. We excluded underweight individuals (BMI < 18.5 kg/m^2; n = 91) and pregnant women (n = 313). All participants provided informed consent, and the NHANES study protocol was approved by the National Center for Health Statistics Research Ethics Review Board.

Energy intake. All participants were asked to complete two 24-h dietary recall interviews, including both weekdays and weekend days. To focus on those not exerting cognitive restraint on food intake, we dietary recall interviews, including both weekdays and weekend days. To focus on those not exerting cognitive restraint on food intake, we

Homeostatic model assessment–insulin resistance and CRP. Blood specimens for measurement of glucose, insulin, and CRP were obtained at the time of the in-person interviews. The specimens were processed, stored at −20°C and shipped to different centers for batched analysis. Specimens for glucose (mg/dL) were analyzed by Collaborative Laboratory Services with the oxygen rate method by using the Beckman Synchron LX20 (12). CVs ranged from 1.2 to 3.6 depending on the lot. Specimens for insulin (μU/mL) were analyzed by Fairview-University Medical Center (Minneapolis, MN) with the human insulin immunoassay by using the Beckman Coulter Biomek 2000 Workstation (13). CVs ranged from 3.4 to 4.9 depending on the lot. Specimens for CRP (mg/dL) were analyzed at the University of Washington Medical Center (Seattle, WA) by nephelometry by using the Dade Behring Nephelometer II Analyzer System (14). CVs ranged from 3.4 to 6.7 depending on the lot. The homeostatic model assessment–insulin resistance (HOMA-IR) was calculated with the following equation: HOMA-IR = (glucose × insulin)/405.

Covariates. All analyses were adjusted for age, education, race/ethnicity, physical activity, and being overweight or obese unless otherwise specified. Education was dichotomized into those who had attended college and those who had a high school degree or less. We coded race/ethnicity as Mexican American, non-Hispanic white, and non-Hispanic black. Because very few respondents described themselves as other Hispanics, other races, or of multiple races, we excluded those individuals (n = 247) to maximize the homogeneity of the racial groups. To account for physical activity, we included the response to the question “Compared with most men/women your age, would you say that you are more active, less active, or about the same?” (15) This question was asked of all participants and was highly correlated with specific questions regarding the frequency, type, and amount of moderate and vigorous physical activity (all P < 0.001). Body mass was included categorically as normal weight (18.5 ≤ BMI < 25 kg/m^2), overweight (25 ≤ BMI < 30 kg/m^2), and obese (BMI ≥ 30 kg/m^2).

Data analyses. Statistical analyses were performed by using Stata software (version 10.0; StataCorp). We used the appropriate survey commands in StATA and applied the recommended sample weights for the data to account for unequal probabilities of selection. Means for percentages and total calories from sugar, nonsugar carbohydrates, protein, SFAs, MUFCs, PUFAs, and alcohol were calculated for men and women. Univariate comparisons between genders with linear regression were performed for each macronutrient and the covariates. Because the change associated with increasing the percentage of calories from 1 macronutrient varied substantially based on the amount of the other macronutrients, we included all macronutrient interaction terms in the linear regression models assessing energy intake. Specifically, we used the Scheffé Quadratic Canonical Polynomial Model to assess the relation between the percentage of calories from the different macronutrients consumed and total energy intake, which allows the change associated with increasing the percentage of calories from 1 macronutrient to vary on the basis of the amounts of the other macronutrients consumed (16). All cross-product interaction terms for all macronutrients were included for the models assessing predicted energy intake. Additionally, we adjusted for the covariates listed above.

The change associated with a 1 percentage point increase in calories across the mean for each macronutrient (from 0.5 percentage points below the mean to 0.5 points above the mean) was calculated, with a corresponding 1-point decrease in percentage of calories from nonsugar carbohydrates. When graphing the results for a given macronutrient, all other macronutrients were held constant at their means unless otherwise specified. Because the relation between percentage of calories from any given macronutrient and predicted energy intake was not constant, we used the “lincom” command in STATA to test whether this 1 percentage point change across the mean was significant. We also calculated the difference in predicted energy intake for a 10 percentage point increase in the percentage of calories from each macronutrient (4 percentage point increase for alcohol) to demonstrate whether clinically important changes in diet composition yielded meaningful differences in predicted energy intake.

Because energy intake decreases as the percentage of calories from protein increases, we also estimated the association of each macronutrient on energy intake when the percentage of calories from protein was decreased to 10% or increased to 20% (from its mean of 15%). These changes in the proportion of calories from protein were off set with additional changes in percentage of calories from nonsugar carbohydrates. We found significant interactions between gender and macronutrient intake when predicting energy intake, and thus provide analyses stratified by gender.

We used linear regression to assess the relation between the percentage of calories from the different macronutrients (the predictor variables) and the HOMA-IR and CRP outcomes. Because of the known
association between BMI and the HOMA-IR and CRP outcomes, we included 1 model (model 1) without the macronutrients and 1 model with the macronutrients (model 2). Model 1 included being overweight or obese and was adjusted for the covariates age, race/ethnicity, education, and physical activity. Model 2 included the macronutrients in addition to the above covariates (and being overweight or obese). The association of increasing the percentage of calories from 1 macronutrient with HOMA-IR and CRP did not vary substantially on the basis of the amounts of the other macronutrients. Therefore, we did not include the macronutrient interaction terms in the regression models assessing HOMA-IR and CRP. We did find significant interactions between gender and macronutrient intake when predicting HOMA-IR and CRP and thus provide analyses stratified by gender.

Results

Demographic characteristics

Demographic characteristics and dietary composition from NHANES 2005–2006 for men and women are presented in Table 1. The distribution of normal-weight, overweight, and obese individuals was different between men and women (P < 0.001). There were small differences in age and racial distribution. Women were more likely to have completed at least some college (P = 0.004). Macronutrient composition was approximately similar between the 2 genders, with the exception of higher alcohol intake among men.

Association of macronutrients with energy intake

Sugar. Figure 1A shows the association of energy intake with increasing percentage of calories from sugar among men. The horizontal axis shows the percentage calories from sugar. Each 1-point increase in percentage of calories from sugar was associated with an equivalent decrease in percentage of calories from nonsugar carbohydrates. The vertical axis shows energy intake. The vertical dotted line in the graph shows that the average male consumes 21.6% of his daily energy intake from sugar. The association between increasing percentages of energy from sugar with predicted energy intake in men (Fig. 1A) and women (Fig. 1B). The vertical dotted line represents the mean. In both men and women, as the percentage of energy from sugar increases from 16% to 28%, that from nonsugar carbohydrates decreases from 37% to 25% when the percentage of energy from protein is 10%, from 32% to 20% when the percentage of energy from protein is 15%, and from 27% to 15% when the percentage of energy from protein is 20%.

FIGURE 1  Associations between increasing percentages of energy from sugar with predicted energy intake in men (A) and women (B). The vertical dotted line represents the mean. In both men and women, as the percentage of energy from sugar increases from 16% to 28%, that from nonsugar carbohydrates decreases from 37% to 25% when the percentage of energy from protein is 10%, from 32% to 20% when the percentage of energy from protein is 15%, and from 27% to 15% when the percentage of energy from protein is 20%.

with an equivalent decrease in percentage of calories from nonsugar carbohydrates. The vertical axis shows energy intake. The vertical dotted line in the graph shows that the average male consumes 21.6% of his daily energy intake from sugar. The association between increasing percentages of energy from sugar with predicted energy intake in men (Fig. 1A) and women (Fig. 1B). The vertical dotted line represents the mean. In both men and women, as the percentage of energy from sugar increases from 16% to 28%, that from nonsugar carbohydrates decreases from 37% to 25% when the percentage of energy from protein is 10%, from 32% to 20% when the percentage of energy from protein is 15%, and from 27% to 15% when the percentage of energy from protein is 20%.

A 1-point increase in percentage of calories from sugar (across its mean) increased energy intake by 23 kcal in men (95% CI: 17, 30 kcal; P < 0.001). Increasing sugar from 17 to 27% increased energy intake by 224 kcal (95% CI: 123, 325 kcal). The relation between sugar and energy intake was relatively constant and remained significant across a range of reasonable percentages of calories from sugar, regardless of protein content. A 1-point increase in percentage of calories from sugar (across its mean) increased energy intake when percentages of calories from protein were 10% (P = 0.04) and 20% (P = 0.001).

A 1-point increase in percentage of calories from sugar (across its mean) increased energy intake by 12 kcal (95% CI: 5, 19 kcal; P = 0.002) among women (Table 2). Increasing sugar from 17% to 27% increased energy intake by 121 kcal (95% CI: 56, 187 kcal). However, the percentage of calories from protein modified the relation between the percentage of calories from sugar and energy intake in women (Fig. 1B). A 1-point increase in the percentage of calories from sugar (across its mean) increased energy intake when the percentage of calories from protein was 10% (P = 0.007) but not when the percentage of calories from protein was 20% (P = 0.14).

SFAs. In men, a 1-point increase in percentage of calories from SFAs (across its mean) significantly increased energy intake by 58 kcal (95% CI: 30, 87 kcal; P = 0.001) (Table 2). Increasing SFAs from 6% to 16% increased energy intake by 569 kcal (95%
CI: 283, 854 kcal). The relation between percentage of calories from SFAs and energy intake was relatively constant and remained significant across the range of reasonable percentages of calories from SFAs (Fig. 2A). A 1-point increase in percentage of calories from SFAs (across its mean) increased energy intake when percentages of calories from protein were 10% (P = 0.02) and 20% (P = 0.004).

In women, a 1-point increase in percentage of calories from SFAs (across its mean) increased energy intake by 27 kcal (95% CI: 5, 49 kcal; P = 0.02) (Table 2). Increasing SFAs from 6% to 16% increased energy intake by 277 kcal (95% CI: 37, 516 kcal). However, the percentage of calories from protein modified the relation between the percentage of calories from SFAs and energy intake in women (Fig. 2B). A 1-point increase in percentage of calories from SFAs (across its mean) had no association with energy intake when percentage of calories from protein was 10% (P = 0.96) but was associated with increased energy intake when percentage of calories from protein was 20% (P = 0.005).

**MUFAs.** A 1-point increase in percentage of calories from MUFAs (across its mean) was associated with a nonsignificant increase in energy intake of 25 kcal (95% CI: 5, 49 kcal; P = 0.11) in men (Table 2). However, the relation between percentage of calories from MUFAs and energy intake was not linear and only became nonsignificant at the mean (Fig. 3A). Any 1-point increase in percentage of calories from MUFAs below their mean was associated with a significant increase in energy intake. For example, energy intake increased by 106 kcal (95% CI: 45, 167 kcal; P = 0.002) when the percentage of calories from MUFAs increased from 8% to 9%.

A 1-point increase in percentage of calories from MUFAs (across its mean) was associated with an increase in energy intake of 36 kcal (95% CI: 9, 63 kcal; P = 0.01) in women (Table 2). As in men, the relation between percentage of calories from MUFAs and energy intake was not linear and the increase in energy intake was greatest at the lowest percentage of calories from MUFAs (Fig. 3B). For example, energy intake increased by 112 kcal (95% CI: 41, 182 kcal; P = 0.004) when the percentage of calories from MUFAs increased from 8% to 9%. Increasing MUFAs from 7% to 17% increased energy intake by 402 kcal (95% CI: 139, 664 kcal).

**PUFAs.** In men, a 1-point increase in percentage of calories from PUFAs (across its mean) increased energy intake by 66 kcal (95% CI: 25, 106 kcal; P = 0.001) (Table 2). The increase in energy intake was not significant when the percentage of calories from protein was 10% (P = 0.16) but was significant when the percentage of calories from protein was 20% (P = 0.009). Increasing PUFAs from 2% to 12% increased energy intake by 651 kcal (95% CI: 252, 1051 kcal). As the percentage of calories from PUFAs increased from 2% to 12% increased energy intake by 651 kcal (95% CI: 252, 1051 kcal).

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**TABLE 2** Association of increasing percentages of calories from different macronutrients (with an equivalent decrease in percentage of calories from nonsugar carbohydrates) on predicted energy intake

<table>
<thead>
<tr>
<th>Macronutrient</th>
<th>Increase of 1 percentage point</th>
<th>Increase of 4 percentage points</th>
<th>Increase of 10 percentage points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Men</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugar</td>
<td>23 (13, 33)</td>
<td>—</td>
<td>224 (123, 325)</td>
</tr>
<tr>
<td>SFAs</td>
<td>59 (30, 87)</td>
<td>—</td>
<td>569 (283, 854)</td>
</tr>
<tr>
<td>MUFAs</td>
<td>25 (–6, 56)</td>
<td>—</td>
<td>298 (–22, 617)</td>
</tr>
<tr>
<td>PUFAs</td>
<td>66 (25, 106)</td>
<td>—</td>
<td>651 (252, 1050)</td>
</tr>
<tr>
<td>Alcohol</td>
<td>38 (23, 54)</td>
<td>153 (92, 215)</td>
<td>—</td>
</tr>
<tr>
<td><strong>Women</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugar</td>
<td>12 (5, 19)</td>
<td>—</td>
<td>121 (56, 187)</td>
</tr>
<tr>
<td>SFAs</td>
<td>27 (5, 49)</td>
<td>—</td>
<td>277 (37, 518)</td>
</tr>
<tr>
<td>MUFAs</td>
<td>36 (9, 63)</td>
<td>—</td>
<td>402 (139, 664)</td>
</tr>
<tr>
<td>PUFAs</td>
<td>43 (30, 57)</td>
<td>—</td>
<td>479 (346, 612)</td>
</tr>
<tr>
<td>Alcohol</td>
<td>25 (7, 43)</td>
<td>90 (23, 156)</td>
<td>—</td>
</tr>
</tbody>
</table>

1 The increase in percentage of calories from each macronutrient (across its mean) is associated with an equivalent decrease in percentage of calories from nonsugar carbohydrates. All other macronutrients were held constant at their means. Estimates were adjusted for age, race/ethnicity, education, and physical activity.

2 The dashes reflect that the incremental change was not calculated for the corresponding macronutrient.
of calories from alcohol (95% CI: 23, 54 kcal; \( P < 0.001 \)) increased energy intake by 25 kcal (95% CI: 23, 54 kcal; \( P < 0.001 \)) (Table 2). Increasing alcohol from 2% to 6% increased energy intake by 153 kcal (95% CI: 92, 215 kcal). The relation between the percentage of calories from alcohol and energy intake was relatively constant and remained significant across a range of reasonable percentages of calories from alcohol (Fig. 5A). A 1-point increase in percentage of calories from alcohol (across its mean) increased energy intake when the percentage of calories from protein was 10% (\( P = 0.003 \)) and 20% (\( P = 0.02 \)).

In women, a 1-point increase in percentage of calories from alcohol (across its mean) increased energy intake by 25 kcal (95% CI: 7, 43 kcal; \( P = 0.002 \)) (Table 2). Increasing alcohol from 1% to 5% increased energy intake by 90 kcal (95% CI: 23, 156). However, the percentage of calories from protein modified the relation between alcohol and energy intake in women (Fig. 5B). A 1-point increase in percentage of calories from alcohol (across its mean) significantly increased energy intake when the percentage of calories from protein was 10% (\( P = 0.007 \)) but not when the percentage of calories from protein was 20% (\( P = 0.48 \)).

Increasing SFAs for MUFAs or PUFAs. Increasing the percentage of calories from SFAs by 1 point (across its mean) with a corresponding decrease in percentage of calories from SFAs was not associated with a change in energy intake in either men (\( P = 0.17 \)) or women (\( P = 0.95 \)). Similarly, increasing SFAs by 1 point (across its mean) with a corresponding decrease in percentage of calories from PUFAs was not associated with a change in energy intake in either men (\( P = 0.61 \)) or women (\( P = 0.15 \)). Finally, increasing PUFAs by 1 point (across its mean) with a corresponding decrease in percentage of calories from MUFAs was not associated with a change in energy intake in either men (\( P = 0.18 \)) or women (\( P = 0.66 \)).

**FIGURE 3** Associations between increasing percentages of energy from MUFAs with predicted energy intake in men (A) and women (B). The vertical dotted line represents the mean. In both men and women, as the percentage of energy from MUFAs increases from 6% to 18%, that from nonsugar carbohydrates decreases from 37% to 25% when the percentage of energy from protein is 10%, from 32% to 20% when the percentage of energy from protein is 15%, and from 27% to 15% when the percentage of energy from protein is 20% from PUFAs increased above the mean, the incremental increase in energy intake was reduced and eventually became nonsignificant (Fig. 4A).

A very similar pattern for the association of PUFAs with energy intake was seen in women. A 1-point increase in percentage of calories from PUFAs increased energy intake by 43 kcal (95% CI: 30, 57 kcal; \( P = 0.001 \)) (Table 2). The increase was not significant when the percentage of calories from protein was 10% (\( P = 0.07 \)) but was significant when the percentage of calories from protein was 20% (\( P = 0.004 \)). Increasing PUFAs from 2% to 12% increased energy intake by 479 kcal (95% CI: 346, 612 kcal). As in men, the increase in energy intake when the percentage of calories from PUFAs increased above the mean became incrementally smaller and eventually nonsignificant (Fig. 4B).

**Alcohol.** In men, a 1-point increase in percentage of calories from alcohol (across its mean) increased energy intake by 38 kcal (95% CI: 23, 54 kcal; \( P < 0.001 \)) (Table 2). Increasing alcohol from 2% to 6% increased energy intake by 153 kcal (95% CI: 92, 215 kcal). The relation between the percentage of calories from alcohol and energy intake was relatively constant and remained significant across a range of reasonable percentages of calories from alcohol (Fig. 5A). A 1-point increase in percentage of calories from alcohol (across its mean) increased energy intake when the percentage of calories from protein was 10% (\( P = 0.003 \)) and 20% (\( P = 0.02 \)).

In women, a 1-point increase in percentage of calories from alcohol (across its mean) increased energy intake by 25 kcal (95% CI: 7, 43 kcal; \( P = 0.002 \)) (Table 2). Increasing alcohol from 1% to 5% increased energy intake by 90 kcal (95% CI: 23, 156). However, the percentage of calories from protein modified the relation between alcohol and energy intake in women (Fig. 5B). A 1-point increase in percentage of calories from alcohol (across its mean) significantly increased energy intake when the percentage of calories from protein was 10% (\( P = 0.007 \)) but not when the percentage of calories from protein was 20% (\( P = 0.48 \)).

**FIGURE 4** Associations between increasing percentages of energy from PUFAs with predicted energy intake in men (A) and women (B). The vertical dotted line represents the mean. In both men and women, as the percentage of energy from PUFAs increases from 1% to 5% increased energy intake by 90 kcal (95% CI: 23, 156). However, the percentage of calories from protein modified the relation between alcohol and energy intake in women (Fig. 5B). A 1-point increase in percentage of calories from alcohol (across its mean) significantly increased energy intake when the percentage of calories from protein was 10% (\( P = 0.007 \)) but not when the percentage of calories from protein was 20% (\( P = 0.48 \)).

**Association of macronutrients with HOMA-IR and CRP**

Higher HOMA-IR values indicate increasing degrees of insulin resistance. Being overweight was associated with an increase in HOMA-IR in men (\( P < 0.001 \)) and women (\( P = 0.001 \)) (Table 3). As expected, being obese was associated with an even greater increase in HOMA-IR in men and in women (both \( P < 0.001 \)). Increasing total energy intake was not associated with an increase in HOMA-IR. The macronutrient composition of the diet had relatively little association with HOMA-IR. The single exception was that an increasing percentage of calories from SFAs was associated with a significant increase in HOMA-IR in women (\( P = 0.02 \)).

Being obese was associated with a significant increase in CRP in both men and women (both \( P < 0.001 \); Table 3). Being overweight was not associated with a significant increase in CRP in men (\( P = 0.18 \)) but was associated with a higher CRP in women (\( P = 0.03 \)). Increasing total energy intake was not associated with an increase in CRP. The macronutrient composition...
of the diet had relatively little association with CRP concentrations. The single exception was that an increasing percentage of calories from PUFAs was associated with a significant decrease in CRP in men ($P = 0.02$).

**Discussion**

Obesity and its complications are the result of excess energy intake, and these outcomes may be influenced by diet composition in the short and long term. The purpose of this study was to assess the association between the proportion of calories from sugar, different fats, and alcohol on energy intake and cardiovascular risk factors. We used an innovative and validated model to assess the associations between macronutrients and energy intake (3,16). This study demonstrated that an increasing percentage of calories from sugar in men and women was associated with significant increases in predicted energy intake. Clinically meaningful differences in energy intake were seen with 10-point changes in the percentage of calories from sugar. Although this was a cross-sectional assessment, our data provide additional evidence to support efforts to decrease sugar consumption as a means to decrease energy intake and prevent weight gain.

We also sought to assess the association between different dietary fats (SFAs, MUFAs, and PUFAs) and energy intake. Two approaches were taken. The first was to increase the percentage of calories from 1 fat while leaving the other 2 fats at their means (increasing the overall percentage calories from fat). By using this approach, substantial increases in energy intake were seen with increases for each of the 3 fats in men and women. There appears to be a plateau for the associated increases in energy intake with increasing percentage of calories from most fats in men and women. The other approach to assessing the association of dietary fats with energy intake was to increase the percentage of calories from 1 fat, with an equivalent decrease in percentage of calories from one of the other fats (leaving the overall percentage of calories from fat the same). There is relatively little evidence about differences between the specific

**FIGURE 5** Associations between increasing percentages of energy from alcohol with predicted energy intake in men (A) and women (B). The vertical dotted line represents the mean. In men, as the percentage of energy from alcohol increases from 0% to 8%, that from nonsugar carbohydrates decreases from 35% to 27% when the percentage of energy from protein is 10%, from 30% to 22% when the percentage of energy from protein is 15%, and from 25% to 17% when the percentage of energy from protein is 20%. In women, as the percentage of energy from alcohol increases from 0% to 5%, that from nonsugar carbohydrates decreases from 34% to 29% when the percentage of energy from protein is 10%, from 29% to 24% when the percentage of energy from protein is 15%, and from 24% to 19% when the percentage of energy from protein is 20%.

**TABLE 3** Association of increasing percentages of calories from different macronutrients and overweight and obesity on HOMA-IR and CRP in adults aged 20–74 y from the 2005–2006 NHANES

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th></th>
<th>Women</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HOMA-IR²</td>
<td>CRP (mg/dL)</td>
<td>HOMA-IR²</td>
<td>CRP (mg/dL)</td>
</tr>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overweight⁴</td>
<td>1.17 (0.85, 1.49)</td>
<td>0.11 (−0.03, 0.26)</td>
<td>0.95 (0.45, 1.46)</td>
<td>0.14 (0.04, 0.24)</td>
</tr>
<tr>
<td>Obese⁵</td>
<td>3.90 (3.12, 4.68)</td>
<td>0.18 (0.11, 0.25)</td>
<td>2.62 (1.52, 3.71)</td>
<td>0.50 (0.37, 0.64)</td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overweight⁴</td>
<td>1.12 (0.70, 1.54)</td>
<td>0.10 (−0.06, 0.26)</td>
<td>0.84 (0.41, 1.27)</td>
<td>0.13 (0.02, 0.25)</td>
</tr>
<tr>
<td>Obese⁵</td>
<td>3.88 (3.22, 4.53)</td>
<td>0.17 (0.09, 0.25)</td>
<td>2.68 (1.61, 3.75)</td>
<td>0.49 (0.34, 0.63)</td>
</tr>
<tr>
<td>Sugar⁶</td>
<td>0.01 (−0.03, 0.06)</td>
<td>0.01 (0.00, 0.02)</td>
<td>0.02 (−0.02, 0.07)</td>
<td>0.00 (0.00, 0.01)</td>
</tr>
<tr>
<td>Protein⁶</td>
<td>0.07 (0.01, 0.14)</td>
<td>0.00 (0.00, 0.01)</td>
<td>0.01 (−0.05, 0.06)</td>
<td>0.00 (−0.01, 0.01)</td>
</tr>
<tr>
<td>SFAs⁷</td>
<td>0.05 (−0.07, 0.17)</td>
<td>0.00 (−0.01, 0.02)</td>
<td>0.10 (0.02, 0.19)</td>
<td>0.00 (−0.03, 0.02)</td>
</tr>
<tr>
<td>MUFAs⁷</td>
<td>0.09 (−0.11, 0.28)</td>
<td>0.02 (−0.01, 0.05)</td>
<td>0.03 (−0.07, 0.13)</td>
<td>0.02 (0.00, 0.05)</td>
</tr>
<tr>
<td>PUFAs⁸</td>
<td>−0.07 (−0.19, 0.05)</td>
<td>−0.01 (−0.03, 0.00)</td>
<td>0.07 (−0.04, 0.19)</td>
<td>0.00 (−0.02, 0.01)</td>
</tr>
<tr>
<td>Alcohol⁹</td>
<td>−0.01 (−0.06, 0.04)</td>
<td>0.00 (0.00, 0.01)</td>
<td>0.00 (−0.04, 0.04)</td>
<td>0.00 (−0.01, 0.01)</td>
</tr>
</tbody>
</table>

¹ Values are β coefficients (95% CIs) from regression models. CRP, C-reactive protein.

² Higher values represent higher values of insulin resistance.

³ Adjusted for race/ethnicity, age, physical activity, and education.

⁴ Values are in relation to normal-weight individuals.

⁵ Adjusted for macronutrients in addition to race/ethnicity, age, physical activity, and education.

⁶ Values represent a 1 percentage point increase in the specified macronutrient with a corresponding 1 percentage point decrease in nonsugar carbohydrates.
fats and their association with energy intake (17,18). Our data support the notion that the specific fat is likely not important in determining energy intake and that decreasing the overall percentage of calories from fat may be the most effective way of decreasing overall energy intake.

The final macronutrient of interest was alcohol, and the results for its association with energy intake are similar to those seen with sugar intake. However, its role in contributing to obesity is uncertain. Alcohol has been previously associated with increasing energy intake (19), but light to moderate drinkers may engage more frequently in healthy behaviors that protect them from becoming obese (20,21). For instance, data from this study show that those who consumed alcohol were more likely to have attended college, reported being more physically active, and were less likely to be obese compared with those who abstained from alcohol. These differences were not seen with the other macronutrients.

We also examined whether macronutrients had a direct association with HOMA-IR and CRP, both validated markers of cardiovascular risk. Being overweight or obese was the primary determinant of HOMA-IR in men and women. After adjusting for being overweight or obese, increasing percentages of calories from sugar, SFAs, MUFAs, PUJAs, and alcohol were not associated with a significant increase in HOMA-IR in men. In women, only an increase in the percentage of calories from SFAs was associated with an increase in HOMA-IR. The association of increasing SFAs in the diet with insulin resistance is somewhat controversial. Some studies have shown that increasing SFAs is associated with increased insulin resistance, whereas others have failed to demonstrate this association (22). Our data indicate that this association may deserve further attention.

Being obese was the primary determinant of CRP concentrations. Increases in CRP were not seen in men or women with increasing percentages of calories from any macronutrient. CRP was lower in men who reported higher proportions of calories from PUFAs. The interpretation of this result is limited by the cross-sectional nature of this study. However, the previous literature suggests that increasing the percentage of calories from PUFAs (with a commensurate reduction in SFAs) reduces cardiovascular events and death (23,24). The potential mechanisms by which increasing PUFAs in the diet might decrease cardiovascular events deserves further exploration.

There are limitations to this study. First, this was a cross-sectional assessment and definitive conclusions cannot be drawn regarding the effect of diet composition on weight gain, the development of obesity, and associations with cardiovascular risk markers. Another potential limitation is the validity of dietary recalls. Some respondents may change their usual dietary patterns because they are a part of a study (25). In particular, obese individuals may be more likely to underreport food intake (10,26). Our own previously published data show that obese individuals reported lower energy intake and had a similar distribution of calories from fat, carbohydrate, and protein compared with normal-weight individuals (3). However, as we also reported, the association of percentage of calories from carbohydrates, fat, and protein on predicted energy intake was essentially identical across normal-weight, overweight, and obese individuals.

Another limitation is that our models assumed a direct and acute effect of diet composition on the outcomes of energy intake, HOMA-IR, and CRP. However, long-term diet composition, which may not be accurately reflected in the dietary recalls, may have an effect on these outcomes even if there is no short-term effect. This may be particularly relevant for the association between diet composition and HOMA-IR and CRP. These measures, which are strongly related to obesity, may be unlikely to change significantly with acute changes in diet composition. However, long-term trends in diet composition may have effects on HOMA-IR and CRP that are independent of obesity and that were not captured in this cross-sectional study.

In conclusion, our results indicate that diet composition is likely to be important in determining energy intake. Increasing the percentage of calories from sugar or any fat was associated with clinically meaningful increases in energy intake. Diet composition appears to have little or no association with HOMA-IR and CRP. However, in the long term, a diet high in sugar and fat might be expected to lead to higher energy intake, weight gain, and the development of obesity in some individuals. It is obesity that is the strongest predictor of these biomarkers of cardiovascular risk and the associated obesity-related complications. Public health and dietary interventions should focus on mechanisms to reduce energy intake, perhaps by limiting sugar and fat intake.

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G.L.A. designed and conducted the research, analyzed data, wrote the manuscript, and had primary responsibility for final content; and P.M.K. conducted the research, analyzed data, and wrote the manuscript. All authors read and approved the final version of the manuscript.

Literature Cited


