Extended use of foods modified in fat and sugar content: nutritional implications in a free-living female population1–3

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ABSTRACT The nutritional implications of the consumption of reduced-fat and reduced-sugar foods were assessed in nonobese, free-living female consumers in a 10-wk intervention trial. Subjects in control (C; n = 13), reduced-fat (RF; n = 17), and reduced-sugar (RS; n = 19) groups, all initially nonusers of reduced-fat and reduced-sugar products, kept 4-d food-intake records to establish energy and macronutrient intakes at baseline and at 2, 4, 7, and 10 wk. Groups RF and RS were instructed to use reduced-fat and reduced-sugar foods, respectively, ad libitum in place of habitually consumed foods with traditional composition, whereas group C was to maintain their usual diet. All foods were purchased by subjects in normal retail outlets and consumed at home. Analyses revealed no main or interactive effect of group on reported energy intake. RF subjects reduced their reported fat intake during the study (P = 0.017) compared with RS and C subjects, and RS subjects reduced their reported sucrose intake compared with RF and C subjects (P = 0.049). Group differences in total sugar intake were not significantly different. All groups reported a small but significant increase in reported protein intake during the study, whereas there were no significant effects on percentage energy from total carbohydrate. Body weights did not change significantly in any group over the study period. These results indicate that, as a single dietary strategy, casual use of macronutrient-substituted foods by consumers under normal eating conditions can significantly influence the macronutrient composition of the diet, but has little net effect on total energy intake or body weight status. Am J Clin Nutr 1997;65:1867–73.

KEY WORDS Fat, sugar, fat substitutes, carbohydrate substitutes, diet, intake, body weight

INTRODUCTION

Many studies have assessed the potential influences of sugar and fat replacement on appetite and energy intake. Most of these data have been collected during short-term (1–14 d) studies, usually based in the laboratory, and most often based on covert manipulations of preloads or foods (1–6). The methods used in most of these studies were oriented toward addressing fundamental phenomena related to the physiologic determinants and correlates of hunger, satiety, and the regulation of energy balance. Such studies provide important information; however, they are not designed to characterize the actual eating behavior of consumers in normal, free-living situations. Biological signals relating to satiety and regulation of energy intake are only one contributor to the variance in eating behavior seen in real-life situations for which many other personal, environmental, and situational factors influence food choice and consumption (7).

Given the considerable academic, public health, and commercial interest in fat and sugar replacement in foods, there are surprisingly few prospective dietary trials or population studies focusing on macronutrient substitution. Beaton et al (8) computed the possible effects of the use of fat and carbohydrate substitutes using models that assume compensatory energy intake by consumption of a mixed diet. Their work suggests that the use of intense sweeteners might result in lower carbohydrate and greater fat intake, whereas fat substitutes would have the opposite effect. However, a major drawback of this type of predictive study is that it must make certain assumptions, eg, that free-living subjects will exhibit complete energy compensation that is not macronutrient-specific and that no unanticipated major shifts in overall food-selection patterns will occur as a result of the availability of nutrient-modified foods. These behavioral assumptions have not been examined by using conventional food products in normal eating situations, although laboratory studies indicate that food-label information may have significant effects on eating behavior (9, 10). In addition, because of the varied composition of real foods, nutrient-modified products might have somewhat different effects on total nutrient intakes than does specific replacement of fat or carbohydrate alone.

Nutrient-modified foods are currently widely available and consumed in the belief that they assist in reducing fat and sugar intakes and in achieving or maintaining an appropriate body weight. However, there are few extended prospective trials that have assessed the effect of fat and sugar replacement on freely selected diets. In most of these studies, subjects were placed on regimens with a relatively fixed composition (11) or enforced intakes (12), or subjects used products as part of a broader effort toward specific nutritional targets (eg, for fat intake or weight loss). Kanders et al (13) reported data from a pilot study suggesting that obese women, but not men, had slightly greater

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weight loss on a 12-wk weight-loss diet that included intense sweeteners. Use of reduced-fat foods has been reported to be easily adopted and highly acceptable, although not necessarily the most effective of several approaches used to achieve reductions in fat intake by subjects given extensive dietary and behavioral counseling (14). Macronutrient replacement or reduction in foods promises a simple, “painless,” and readily maintained means for reducing sugar and fat intakes, but there has been little evaluation of the situation in which modified foods are consumed more casually as part of a “normal” diet, as opposed to a diet aimed at specific weight loss or a diabetic or low-fat diet.

In a recent multicenter intervention trial, nonobese subjects were assigned to groups encouraged to consume a high number of full-fat or equivalent reduced-fat commercial food products for 6 mo, provided by outlets set up at the research centers (15). The main dietary outcome was that subjects who consumed reduced-fat foods reduced their intakes of fat but not energy, and had no significant changes in body weight over the study period. The design gave control subjects free access to a wide range of full-fat items, and these subjects increased their fat and energy intakes significantly and gained weight.

In a prospective dietary trial carried out in our laboratory, free-living consumers purchased their own foods from retail supermarkets and consumed them ad libitum at home for 6 wk (16). Relative to control subjects, those who were advised to make extensive substitutions of reduced-fat for full-fat foods immediately and consistently maintained a substantial reduction in the percentage energy from fat. Carbohydrate and protein intakes spontaneously increased such that overall energy intakes did not differ significantly from those of control subjects. The present study was designed to expand and extend this previous study while also contrasting the effects of fat and sugar replacement.

SUBJECTS AND METHODS

Subjects

The subject population initially consisted of 65 females aged 18–50 y, recruited by public advertisement. Before beginning the study, all prospective participants were screened by questionnaire to exclude any individuals who were pregnant or lactating, following any modified diet for medical reasons or for weight loss, or obese [body mass index (BMI; in kg/m²) > 30] (17) or underweight (BMI < 18). Because of the extended duration of the study, subjects were asked about their plans for vacation to avoid disruption due to time spent away from home. In addition, a series of questions was asked regarding the frequency of use of various reduced-fat and reduced-sugar foods to exclude individuals who already habitually consumed high amounts of these foods and to ensure that there would be sufficient scope to modify fat or sugar intake.

The protocol was reviewed and approved by the Institute of Food Research Human Research and Ethics Committee.

Study protocol

The study involved a 2-wk baseline period followed by 10 wk of intervention. During the baseline period all subjects continued with their habitual diet and were familiarized with the requirements of the study. All subjects completed the dietary-restraint component of the Dutch Eating Behaviour Questionnaire (18). At the first visit subjects received detailed instruction and training in keeping food-intake diaries using a digital dietary balance (Soehnle quanta, model 8021; CMS Weighing Equipment Ltd, London). Subjects kept weighed diet records on 4 consecutive days (including a weekend day) during the baseline period (week 0) and on 4 d at the end of intervention weeks 2, 4, 7, and 10. This level of dietary data collection was selected so as to minimize the level of inconvenience to the subject while achieving, we hope, a representative measure of food and nutrient intakes over the short- and longer-term periods. The baseline food-intake data were also used as a second check to eliminate individuals who, although they had reported a low frequency of consumption of reduced-fat and reduced-sugar foods in the screening questionnaire, did in fact consume large quantities of these products; however, no volunteers were excluded for this reason. In addition, all subjects were requested to retain their grocery checkout receipts for later analysis and as an additional check on compliance.

After the baseline period, subjects were assigned to one of three groups: control (C; n = 18), reduced fat (RF; n = 22) and reduced sugar (RS; n = 25). The dietary data from 2 subjects (one each from groups C and RS) were excluded on the basis of inadequate information, and further analyses were carried out on the remaining 63 subjects. It has become apparent that a high proportion of subjects in dietary trials self-report intakes that are well below the habitual intake required to maintain energy balance (19–21). In an effort to minimize the effect of misreporting on the overall results, an additional 14 subjects (4 from group C and 5 each from groups RF and RS) were removed from the analyses on the basis of the following criteria: 1) baseline energy intake/estimated basal metabolic rate (BMR) < 1.10, 2) baseline energy intake/estimated BMR for weeks 2–10 < 1.14 and a weight loss < 0.5 kg, and 3) within-subject baseline energy intake/estimated BMR variance exceeding the between-subjects variance across the intervention period.

On the basis of criterion 1, six subjects were removed whose baseline data were unlikely to be a valid reflection of their true, normal intake (22). On the basis of criterion 2, five subjects were removed whose low reported intake over the reporting period was not confirmed by significant weight loss. On the basis of criterion 3, three subjects were removed who reported extreme variance in intake across different recording periods.

Study groups

In addition to two baseline visits, all subjects attended the laboratory at the end of weeks 2, 4, 7, and 10 of the intervention period. Body weight and height were measured at each visit by using a double-sided, eye-level balance with telescopic measuring rod (model 7120; Seca Ltd, Birmingham, United Kingdom), and BMI was calculated. In a one-to-one discussion at each visit, the investigator checked through the diet-record booklets to establish that the information was complete and that any unclear items were identified. Subjects retained the packaging or labels of unusual foods so that the manufacturer’s nutrient-composition data could be obtained and added to the dietary database.

The sequence of 4-d diet records collected in each period were coded and analyzed for energy, total fat, total carbohydrates, total and individual sugars, protein, and nonstarch
polysaccharide. Food-composition data were obtained by using published tables (23) together with available manufacturer’s data. All foods were classified into one of 37 food groups (with separate groups for reduced-fat or reduced-sugar foods) and analyses of these data were used to estimate major food sources of macronutrients and energy.

RF group

Each member of the RF group was seen individually by a researcher and provided with detailed instructions regarding the replacement of traditional full-fat items with reduced-fat alternatives, which were widely available at local supermarkets. On the basis of baseline dietary records, subjects were provided with lists of regular food products together with their reduced-fat alternatives and specifically requested to replace traditional items with the modified-fat version. Subjects were advised that they could certainly use other reduced-fat products that had not been listed, but they were not specifically instructed to purchase any particular food items that were not already part of their habitual diet. No further definitions of “low” or “reduced” were given because most commercial products are clearly labeled and identification of such products would not have been difficult. There was no limitation on, or instruction against, consuming other foods high in fat or, indeed, the conventional versions of reduced-fat items. No further dietary advice was given.

RS group

Instructions to subjects in the RS group were the same as for the RF group except that reduced-sugar foods were substituted for the conventional sugar-containing foods. As for the RF groups, lists detailing appropriate substitutions were provided for each subject on the basis of baseline dietary records, with subjects having the option to use other RS (or full-sugar) products as desired.

Control group

Subjects in the control group were given no special dietary instructions and were to continue to follow their habitual diet during the intervention period. These data were used to control for possible secular changes in diet and the effects of repeated diet-record collection. This level of control was particularly important because of the extended period of intervention.

Statistical analysis

After removal of subjects confirmed to have misreported their dietary intake during the study (on the basis of the criteria given previously), analyses presented here were carried out on 49 subjects (group RF, n = 17; group RS, n = 19; and group C, n = 13) who completed the entire protocol. The overall experiment was analyzed by full-factorial repeated-measures analysis of variance (ANOVA) for main and interactive effects of group and time (SPSS version 6.1 for Windows; SPSS Inc, Chicago). One-way ANOVA with least-significant-difference tests was used to compare baseline values and also for post hoc analyses of selected significant repeated-measures ANOVA results, testing for group differences in change from baseline at the four specific time points during the intervention period. The trial had a 90% probability of detecting approximate single-point changes from baseline in energy intake of 1.25 MJ, an absolute change of 5% of energy from fat, an absolute change of 3% of energy from sucrose, and a change in body weight of 0.4 kg (P = 0.05). The power of the overall repeated-measures analyses should exceed these estimates for single time points. All data are presented as means ± SEMs and a value of P < 0.05 was used as the criterion for statistical significance.

RESULTS

There were no significant group differences at baseline in age, weight, BMI, or dietary-restraint scores (Table 1). Similarly, there were no significant group differences at baseline in total energy intake or percentage of energy from fat, total carbohydrate, sucrose, total sugars, starch, protein, or non-starch polysaccharide (Table 2).

Energy and macronutrient intakes

There were no significant overall main or interactive effects of group for energy intake (Figure 1). However, there was a significant effect of time (P < 0.001): energy intake decreased similarly in all three groups such that final mean reported energy intakes were 85% of baseline values. This reduction over the course of the intervention period for all groups appeared to be a reflection of repeated record keeping, particularly because the greatest deficit was observed at week 10 (−1.15 MJ for group C, −1.22 MJ for group RF, and −1.37 MJ for group RS compared with baseline values). Similar reductions in reported energy intake were obtained in a shorter trial with reduced-fat foods (16). Because changes in energy intakes did not differ significantly between groups, there were no meaningful differences between analyses of macronutrient intakes based on absolute grams or expressed as percentage of energy; the latter are presented here.

Compared with the RS and C groups, the RF group reduced their fat intake significantly during the intervention period from ~37% of energy from fat at baseline to 33% of energy from fat at week 10 (P = 0.017) (Figure 2). This reduction was not fully consistent across the study period because significant reductions in fat intake in the RF group were seen at weeks 2, 7, and 10 but not at week 4, at which time values were close to baseline. The anomalous result at week 4 was not due to a single event (since subjects started on different dates), but was due in part to exceptionally high rises in total fat intake in two RF subjects during that recording period. Analyses of changes in intake from specific food groups show that the reduction in fat intake by the RF group came primarily from milk and milk products, fats and oils (including spreads and dressings), and

| TABLE 1 | Age, BMI, and dietary restraint characteristics at baseline in the three groups
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>C (n = 13)</td>
<td>RF (n = 17)</td>
<td>RS (n = 19)</td>
</tr>
<tr>
<td>Age (y)</td>
<td>34.5 ± 8.4</td>
<td>36.8 ± 7.6</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.2 ± 3.3</td>
<td>22.7 ± 3.1</td>
</tr>
<tr>
<td>Dietary restraint$^2$</td>
<td>2.8 ± 0.8</td>
<td>2.4 ± 0.9</td>
</tr>
</tbody>
</table>

$^1$ ± SEM. C, control group; RF, reduced-fat group; RS, reduced-sugar group. There were no significant difference by ANOVA.

$^2$ Measured by the Dutch Eating Behaviour Questionnaire (18), with a range of 1 (low) to 5 (high).
TABLE 2
Reported energy and macronutrient intakes at baseline

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>C (n = 13)</th>
<th>RF (n = 17)</th>
<th>RS (n = 19)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (MJ/d)</td>
<td>9.3 ± 0.4</td>
<td>8.3 ± 0.2</td>
<td>8.7 ± 0.4</td>
</tr>
<tr>
<td>Total fat (g/d)</td>
<td>82 ± 5</td>
<td>81 ± 4</td>
<td>79 ± 3</td>
</tr>
<tr>
<td>(% of energy)</td>
<td>34 ± 4</td>
<td>37 ± 5</td>
<td>35 ± 5</td>
</tr>
<tr>
<td>Total carbohydrate (g/d)</td>
<td>278 ± 13</td>
<td>236 ± 6</td>
<td>262 ± 10</td>
</tr>
<tr>
<td>(% of energy)</td>
<td>51 ± 5</td>
<td>48 ± 4</td>
<td>51 ± 5</td>
</tr>
<tr>
<td>Sucrose (g/d)</td>
<td>55 ± 6</td>
<td>48 ± 4</td>
<td>58 ± 5</td>
</tr>
<tr>
<td>(% of energy)</td>
<td>10 ± 1</td>
<td>10 ± 1</td>
<td>11 ± 1</td>
</tr>
<tr>
<td>Total sugar (g/d)</td>
<td>127 ± 12</td>
<td>106 ± 5</td>
<td>124 ± 5</td>
</tr>
<tr>
<td>(% of energy)</td>
<td>23 ± 6</td>
<td>21 ± 4</td>
<td>24 ± 7</td>
</tr>
<tr>
<td>Starch (g/d)</td>
<td>149 ± 27</td>
<td>130 ± 13</td>
<td>136 ± 27</td>
</tr>
<tr>
<td>(% of energy)</td>
<td>27 ± 4</td>
<td>27 ± 3</td>
<td>27 ± 5</td>
</tr>
<tr>
<td>Protein (g/d)</td>
<td>81 ± 4</td>
<td>72 ± 3</td>
<td>70 ± 3</td>
</tr>
<tr>
<td>(% of energy)</td>
<td>15 ± 3</td>
<td>15 ± 3</td>
<td>14 ± 2</td>
</tr>
<tr>
<td>NSP (g/d)</td>
<td>16 ± 2</td>
<td>13 ± 1</td>
<td>13 ± 1</td>
</tr>
</tbody>
</table>

* X ± SEM. C, control group; RF, reduced-fat group; RS, reduced-sugar group; NSP, non-starch polysaccharide. There were no significant differences by ANOVA.

meat and meat products, in that order, even after increased fat intakes from the reduced-fat versions of these foods were accounted for.

There was no group × time effect on total carbohydrate intake (P = 0.4), although at week 10 the difference in total carbohydrate intake between the RS and RF groups was nearly significant (P = 0.07) (Figure 3). There was no significant group × time effect on nonstarch polysaccharide intake (P = 0.72), although there was a significant effect of time (P = 0.019). There was no significant group × time effect on percentage of energy from starch (P = 0.44).

There was a significant group × time effect for changes in percentage of energy from sucrose (P = 0.049) (Figure 4), with the RS group having a reduced sucrose intake relative to the C group at weeks 4 and 10 and relative to the RF group at all intervention periods. There were no significant group × time effects on total sugar intake (P = 0.37); however, all groups reduced their reported sugar intake during the study (P = 0.001). The RS group reduced their percentage of energy from sugar to a greater extent than did the RF or C groups, but this difference was not significant. There were also no significant group × time effects on total sugars as a percentage of total carbohydrate (P = 0.46).

There were no significant group × time effects on percentage of energy from protein (P = 0.83) but there was a significant effect of time (P = 0.016), with protein intakes increasing slightly from baseline throughout the period of intervention in all groups (Figure 5). This change was not correlated with changes in reported energy intakes, and therefore does not

FIGURE 1. Mean (± SEM) change from baseline of reported total energy intake for control (●), reduced-fat (○), and reduced-sugar (△) groups.

FIGURE 3. Mean (± SEM) change from baseline of reported total carbohydrate intake for control (●), reduced-fat (○), and reduced-sugar (△) groups.
EFFECTS OF NUTRIENT-MODIFIED FOODS

FIGURE 4. Mean (± SEM) change from baseline of reported sucrose intake for control (●), reduced-fat (○), and reduced-sugar (△) groups.

FIGURE 5. Mean (± SEM) change from baseline of reported protein intake for control (●), reduced-fat (○), and reduced-sugar (△) groups.

FIGURE 6. Mean (± SEM) change from baseline of body weight of control (●), reduced-fat (○), and reduced-sugar (△) groups.

seem to be linked specifically to the apparent underreporting with time, and may represent a secular change in diets.

Anthropometric measures

There were no significant time or group × time effects on body weight (P = 0.563) (Figure 6) and, therefore, no effects on BMI.

DISCUSSION

The use of commercial reduced-fat foods over 10 wk by free-living consumers in their normal environment was associated with significant reductions in fat intakes toward intakes recommended currently (24). The use of reduced-sugar foods in this study led to significant reductions in sucrose intake, but not in intake of total sugars. Neither approach led to identifiable changes in total energy intakes or body weights. This is one of the few studies to prospectively examine the effects of the extended use of modified foods in the domestic environment over a period sufficient for adaptation to the diet and for significant changes in energy balance to have been detected in body weight. The focus on freely selected commercial foods was a major feature that differentiated this study from other studies in which investigators fixed or prescribed diets or provided their subjects with specific foods (11, 12).

Subjects were advised, on the basis of baseline dietary records, of appropriate substitutions that were possible within their preexisting habitual diet, and were also encouraged to use other modified foods not highlighted in this way. It is clear from the results of this and other studies (15, 16) that the number and composition of available products was sufficient to generate a significant change in macronutrient intakes. The maximum response was determined partly by the foods available (their acceptability and the degree of macronutrient modification), but perhaps as much as or more by the preexisting food habits of individuals. The level of fat reduction achieved in this study was somewhat smaller than what we observed in a study of similar design but of shorter duration (13), and this difference in magnitude of response almost certainly reflected the lower baseline fat intakes of the present subject population. Subgroup analyses of these data (25) and data from a large multicenter trial of reduced-fat foods (26) suggest that reductions in fat intake by using reduced-fat foods occur largely among subjects who had high fat intakes initially, with little change seen among those individuals with initial intakes < 35% of energy. Although some regression toward the mean was expected, this outcome appears to be an important consideration in designing future trials, and may also raise questions about the behavioral response to use of these products by individuals whose diet is already moderate or low in fat content. All of these trials found that subjects maintained energy balance when consuming reduced-fat foods under these realistic conditions.

Use of reduced-sugar foods led to a substantial effect on sucrose intake, but a more modest effect on total sugars that was nearly significant. Overall, these results suggest that use of RS foods may have a modest effect on intake of major macronutrient classes in the absence of other, willful efforts to control overall diet. Data from experimental studies (27, 28) and theoretical arguments (8, 28) suggest that replacement of sugars with intense sweeteners might lead to a higher propor-
tion of dietary energy being derived from fat. Subgroup analyses of the present data provide some evidence in support of this (25), but only among subjects with an initially low fat or high sucrose intake. However, although low sugar intakes are commonly associated with high fat intakes (29–32), the limited population data available do not support a link between intense sweetener use and either sugar or fat intakes (28, 33). This suggests the likelihood that many reduced-sugar foods in practice are simply added to a preexisting diet rather than specifically used to replace sugar-containing foods. Because many common reduced-sugar products have a minimal macronutrient or energy content, the effect of intense sweeteners on sugar intake or, indeed, intakes of any macronutrients, could thus appear negligible.

In suggesting maintenance of energy balance without macronutrient-specific compensation, the present results broadly agree with the outcomes of more highly controlled, laboratory-based studies (1–6). However, such studies are not designed primarily to assess overall consumer responses to the availability and use of commercially available modified foods, and typically constrict potential behavioral cues and response options (34). Laboratory studies have also led to tremendous debates over points of methodology, in part because of the presumed implications for commercial marketing and public health. Because recommendations for a reduction in fat intake and a stabilization or reduction in sugars intake are provided to the general public, it is important to move outside the laboratory to establish how the availability and purchasing of nutrient-modified foods could influence dietary intake and progress toward achieving dietary goals.

Although consumer trials hold potentially high ecologic validity, they may be criticized for low control and particularly for their dependence on self-reported data. In the present study, despite the use of measures to exclude obvious misreporters of food intake, reported energy intakes nevertheless decreased over the trial and were inconsistent with the lack of change in body weight. A consistent change from baseline of only 0.5 MJ/d would have corresponded to a weight change of >1.0 kg over 10 wk, assuming no changes in energy expenditure, an assumption supported by other research (35). Detection of such differences in weight, if they had occurred, was well within the power of the study, and therefore offers a relatively robust response measure. Underreporting during the intervention trial appears primarily to be an effect of repeated diet collection, given the degree to which it (equally) occurred in all groups. In the absence of precise objective data on energy expenditure and body composition, the criteria available for identifying and removing underreporters was relatively crude and conservative. Inclusion of an appropriate control group and an extended time frame greatly aided the interpretation of the results, but it is clear that these types of consumer trials would benefit from the development of more reliable methods of measuring habitual eating behavior.

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REFERENCES