Dietary energy density is associated with energy intake and weight status in US adults

Jenny H Ledikwe, Heidi M Blanck, Laura Kettel Khan, Mary K Serdula, Jennifer D Seymour, Beth C Tohill, and Barbara J Rolls

ABSTRACT
Background: Laboratory-based investigations indicate that the consumption of foods with a low energy density (kcal/g) decreases energy intake. Although low-energy-dense diets are recommended for weight management, relations between energy density, energy intake, and weight status have not been clearly shown in free-living persons.

Objectives: A representative US sample was used to determine whether dietary energy density is associated with energy intake, the weight of food consumed, and body weight and to explore the influence of food choices (fruit, vegetable, and fat consumption) on energy density and body weight.

Design: A cross-sectional survey of adults (n = 7356) from the 1994–1996 Continuing Survey of Food Intakes by Individuals and two 24-h dietary recalls were used.

Results: Men and women with a low-energy-dense diet had lower energy intakes (≈425 and 275 kcal/d less, respectively) than did those with a high-energy-dense diet, even though they consumed more food (≈400 and 300 g/d more, respectively). Normal-weight persons had diets with a lower energy density than did obese persons. Persons with a high fruit and vegetable intake had the lowest energy density values and the lowest obesity prevalence.

Conclusions: Adults consuming a low-energy-dense diet are likely to consume more food (by weight) but to have a lower energy intake than do those consuming a higher-energy-dense diet. The energy density of a variety of dietary patterns, including higher-fat diets, can be lowered by adding fruit and vegetables. Our findings support the hypothesis that a relation exists between the consumption of an energy-dense diet and obesity and provide evidence of the importance of fruit and vegetable consumption for weight management.

KEY WORDS Energy density, obesity, weight management, food patterns, fruit and vegetables, Continuing Survey of Food Intakes by Individuals, CSFII

INTRODUCTION
Diet and physical activity are the cornerstones of weight management. Dietary strategies recommended for weight loss have traditionally focused on decreasing portion sizes and reducing fat intakes (1, 2). Advice to “eat less” may, however, result in feelings of hunger and dissatisfaction. Furthermore, compliance with this type of dietary regimen can be challenging, given the pervasiveness of large portions of palatable, high-calorie foods in today’s society. Recently, several prominent health-related organizations have recommended an alternative approach to decreasing energy intake, ie, the consumption of foods with a low energy density, which provide relatively little energy (kcal/g) in a standard amount of food (3). The nationally representative study we describe herein is the first investigation of the relations between energy density and weight status that explores how the major determinants of energy density (fruit, vegetable, and fat intakes) are related to obesity.

Energy density refers to the amount of energy in a given weight of food. Foods with a low energy density provide less energy per gram than do foods with a high energy density. Studies indicate that people tend to consume a fairly consistent weight of food over the course of a few days; therefore, the consumption of low-energy-dense foods that contain less energy per gram may decrease overall energy intakes (4). Multiple laboratory-based studies have confirmed that people consume less energy when they are presented with foods that have a lower energy density than when they are offered similar foods with a higher energy density (5–10). Few studies, however, have investigated whether energy density influences total energy intake in free-living persons, and even fewer studies have investigated associations with weight status (11, 12).

To develop effective dietary strategies for weight management, we need to understand how energy density and weight status are influenced by food choices. Consuming water- and

1 From the Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Division of Nutrition and Physical Activity, Atlanta, GA (JHL, HMB, LKK, MKS, JDS, and BCT), and the Department of Nutritional Sciences, The Pennsylvania State University, University Park, PA (JHL and BJR).
2 The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the funding agency.
3 Supported in part by the National Institutes of Health grant R37DK039177 (BJR) and by an appointment to the Research Participation Program at the Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Division of Nutrition and Physical Activity, which was administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the US Department of Energy and the Centers for Disease Control and Prevention (JHL).
4 Reprints not available. Address correspondence to JH Ledikwe, The Pennsylvania State University, 226 Henderson Building, University Park, PA 16802. E-mail: mvh111@psu.edu.
Received September 29, 2005.
Accepted for publication February 14, 2006.

fiber-rich foods, such as fruit and vegetables, is one strategy for decreasing the energy density of the diet, because water and fiber contribute weight to food with limited energy (13). Another strategy is to limit high-fat foods, because fat (9 kcal/g) adds substantially more energy to food than does water (0 kcal/g), fiber (1.5–2.5 kcal/g), carbohydrate (4 kcal/g), or protein (4 kcal/g) (13). Because fat is highly palatable, however, extreme reductions in fat intake may be difficult for some people to maintain. Whether a high consumption of water-rich and fiber-rich foods can substantially lower the energy density of a diet that is higher in fat has yet to be determined. To better understand strategies that patients could use to lower the energy density of their diet, we need information on how the consumption of different amounts of fruit and vegetables and of fat is related to energy density and weight status (14, 15).

The purpose of this investigation was to use a nationally representative sample of noninstitutionalized adults to test the hypothesis that the energy density of the diet is associated with total energy intake, the weight of food consumed, and body weight. We also explored the influence of fruit, vegetable, and fat intakes on energy density and body weight.

SUBJECTS AND METHODS

Sample

We used data from the 1994–1996 Continuing Survey of Food Intakes by Individuals—a 2-d survey conducted by the US Department of Agriculture (USDA) (16). The USDA employed a complex, multistage probability sampling design to obtain a nationally representative sample of noninstitutionalized individuals in the United States (16). The response rates for day 1 and day 2 were 80.0% and 76.1%, respectively. Data from adults aged >19 y who completed both dietary recalls were considered for inclusion in these analyses. After exclusion of participants who had missing anthropometric data (n = 144) or reported consuming no foods on either day (n = 35), being pregnant or lactating (n = 101), or following a special diet (n = 1694), 7356 persons were left in the analytic sample. Sociodemographic information for these participants, by sex, is shown in Table 1. The study was conducted according to the ethical guidelines of The Pennsylvania State University.

Dietary and weight status data

Data on dietary intake were collected through interviewer-administered 24-h recalls with a multiple pass technique to obtain in-depth information about the foods and beverages consumed on 2 nonconsecutive days, 3–10 d apart (16). Measuring guides were used to help respondents estimate the amounts of food and beverage consumed. Energy and nutrient values were based on the USDA Nutrient Database for Standard Reference, release 11 (17). Servings of fruit and vegetables were based on serving sizes from the Food Guide Pyramid (18) and were determined using the Pyramid Servings Database developed by the USDA (19). A recent review article emphasizes the importance of attention to food preparation methods when exploring relations between food intake and weight status (15). Therefore, when quantifying servings of fruit and vegetables, we did not include fried and dried fruit and vegetables, which generally have a high energy density and a high calorie content, or juices, which are less satiating than are whole fruit and vegetables; including these food groups may have limited the interpretation of our findings (15).

Results of an earlier study indicated that the inclusion of beverages when calculating the energy density of a diet may diminish associations with outcome variables because of increased day-to-day variance within individual respondents (20). Therefore, energy density values were calculated based only on food intake, excluding all beverages. As described previously (20), total energy intake from the food consumed for each of the 2 d was divided by the total weight of the food reported. Values for energy density from day 1 and day 2 were averaged to derive a mean value for each participant. Because beverages are a substantial source of energy for some people, energy intake from beverages was also examined as an outcome, even though beverages were not included in the calculation of energy density.

Body mass index (BMI) values were computed as weight (kg) divided by height squared (m). Weight and height measures were self-reported. Participants were classified by BMI as being normal weight (≤24.9), overweight (25.0–29.9), or obese (≥30.0) (2).

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Sociodemographic profiles of the study participants by sex</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men (n = 3971)</td>
</tr>
<tr>
<td>Age group</td>
<td>n (%)</td>
</tr>
<tr>
<td>20–29 y</td>
<td>675 (17)</td>
</tr>
<tr>
<td>30–39 y</td>
<td>753 (19)</td>
</tr>
<tr>
<td>40–49 y</td>
<td>701 (18)</td>
</tr>
<tr>
<td>50–59 y</td>
<td>662 (16)</td>
</tr>
<tr>
<td>60–69 y</td>
<td>616 (16)</td>
</tr>
<tr>
<td>≥70 y</td>
<td>562 (14)</td>
</tr>
<tr>
<td>Race-ethnicity</td>
<td></td>
</tr>
<tr>
<td>Non-Hispanic white</td>
<td>3098 (78)</td>
</tr>
<tr>
<td>Non-Hispanic black</td>
<td>376 (10)</td>
</tr>
<tr>
<td>Hispanic</td>
<td>355 (9)</td>
</tr>
<tr>
<td>Asian or Pacific Islander</td>
<td>94 (2)</td>
</tr>
<tr>
<td>Other</td>
<td>48 (1)</td>
</tr>
<tr>
<td>Annual income</td>
<td></td>
</tr>
<tr>
<td>0–130%</td>
<td>841 (21)</td>
</tr>
<tr>
<td>131–350%</td>
<td>1601 (40)</td>
</tr>
<tr>
<td>&gt;350%</td>
<td>1529 (39)</td>
</tr>
<tr>
<td>Region of the United States</td>
<td></td>
</tr>
<tr>
<td>Northeast</td>
<td>668 (17)</td>
</tr>
<tr>
<td>Midwest</td>
<td>944 (24)</td>
</tr>
<tr>
<td>South</td>
<td>1461 (37)</td>
</tr>
<tr>
<td>West</td>
<td>878 (22)</td>
</tr>
<tr>
<td>Education</td>
<td></td>
</tr>
<tr>
<td>&lt; High school graduate</td>
<td>804 (20)</td>
</tr>
<tr>
<td>High school graduate</td>
<td>1318 (34)</td>
</tr>
<tr>
<td>Some post–high school education</td>
<td>813 (21)</td>
</tr>
<tr>
<td>College graduate</td>
<td>984 (25)</td>
</tr>
<tr>
<td>Current smoker</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>1143 (29)</td>
</tr>
<tr>
<td>No</td>
<td>2823 (71)</td>
</tr>
<tr>
<td>Exercise</td>
<td></td>
</tr>
<tr>
<td>5–7 times/wk</td>
<td>2318 (33)</td>
</tr>
<tr>
<td>2–4 times/wk</td>
<td>858 (22)</td>
</tr>
<tr>
<td>1–4 times/mo</td>
<td>498 (13)</td>
</tr>
<tr>
<td>Rarely or never</td>
<td>1283 (32)</td>
</tr>
</tbody>
</table>

1 Percentage of the poverty threshold.
2 Significantly different from men, P < 0.05 (chi-square test).
Statistical analyses

The data were analyzed by using SAS-callable SUDAAN software (release 8.02, 2003; Research Triangle Institute, Research Triangle Park, NC). Because standard definitions describing a person’s diet based on energy density have not been developed, we used sex-specific tertile cutoffs to classify the diets of both men and women as having a low, medium, or high energy density. To test for differences by these 3 categories for categorical and continuous variables, we used chi-square and analysis of variance tests, respectively. Covariates included in the analyses with continuous variables included age group (20–29, 30–39, 40–49, 50–59, 60–69, or ≥70 y), race-ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic, Asian Pacific Islander, or other), region of the United States (northeast, midwest, south, or west), annual income expressed as a percentage of the poverty threshold (0–130%, 131–350%, or >350%), highest level of education (less than high school, high school, ≥4 y of college), frequency of exercising vigorously (<1 time/ mo, 1–5 times/mo, 2–4 times/wk, or ≥5 times/wk), and current smoking status (yes or no). To explore differences by fruit, vegetable, and fat intakes, the subjects were categorized on the basis of the consumption of fruit and vegetables (<5, 5–9, or >9 servings/d) and fat intake (≤30% or >30% of energy from fat). Estimated percentages, means, CIs, and comparisons were based on weighted observations that reflected the probability of selection, nonresponse, and adjustments following stratification. *P* values ≤0.05 were considered significant.

RESULTS

Low-, medium-, and high-energy-dense diets

Sex-specific tertile cutoffs were used to classify participants by the energy density of their diet (low, medium, or high). For men, low-, medium-, and high-energy density were defined by mean daily values for energy density of <1.7, 1.7–2.1, and >2.1 kcal/g, respectively. The corresponding values for women were <1.6, 1.6–2.0, and >2.0 kcal/g.

Men and women with a low-energy-dense diet had a lower mean intake of total energy, energy from food, and energy from beverages than did their counterparts with a medium- or high-energy-dense diet (Table 2). The estimated total energy intake from food and beverages for men with a low-energy-dense diet was 432 kcal/d less than that for men with a high-energy-dense diet. Similarly, energy intake for women with a low-energy-dense diet was an estimated 278 kcal/d less than that for their counterparts with a high-energy-dense diet. Men and women with a low-energy-dense diet consumed an estimated 396 and 295 g/d more food, respectively, than did their peers with a high-energy-dense diet (Table 2), and these differences were significant. In contrast, men and women with a low-energy-dense diet drank fewer grams per day of nonwater beverages than did those with a medium- or high-energy-dense diet.

Women with a low-energy-dense diet had lower mean BMI values and body weights than did women with a high-energy-dense diet (Table 3). In contrast, these measures did not differ by category of energy density for men. Even so, the prevalence of obesity was 6% lower for men with a low-energy-dense diet than for their counterparts with a high-energy-dense diet. Similarly, energy intake for men with a low-energy-dense diet was an estimated 278 kcal/d less than that for their counterparts with a high-energy-dense diet. Men and women with a low-energy-dense diet consumed an estimated 396 and 295 g/d more food, respectively, than did their peers with a high-energy-dense diet (Table 2), and these differences were significant. In contrast, men and women with a low-energy-dense diet drank fewer grams per day of nonwater beverages than did those with a medium- or high-energy-dense diet.

Dietary patterns characterized by intake of fruit, vegetables, and fat

To improve our understanding of the different food choices that people can use to lower the energy density of their diet, dietary patterns characterized by fruit and vegetable intake (<5, 5–9, or >9 servings/d) and fat intake (≤30% or >30% of energy from fat/d) were analyzed. There was a significant interaction between fruit and vegetable intake and fat intake (*P* < 0.03); therefore, subjects were stratified into subgroups based on both of these variables. The energy density of food patterns stratified by intake of fruit and vegetables and fat intake are presented for men and women combined in Figure 2; the findings were similar for men and women individually. Within the 2 categories of fat intake, the overall percentage of energy from fat did not differ by consumption of fruit and vegetables, but persons with a diet high

<table>
<thead>
<tr>
<th>TABLE 2</th>
<th>Energy intakes and weight of food and beverages for men and women consuming a low-, medium-, or high-energy-dense diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td>Low, &lt;1.7 kcal/g (n = 1323)</td>
</tr>
<tr>
<td>Energy from food and beverages (kcal/d)</td>
<td></td>
</tr>
<tr>
<td>Total food and beverage energy</td>
<td>2213 ± 30</td>
</tr>
<tr>
<td>Food energy</td>
<td>1828 ± 25</td>
</tr>
<tr>
<td>Beverage energy</td>
<td>386 ± 13</td>
</tr>
</tbody>
</table>

1. All values are expressed as ± SE and were adjusted for age group, race-ethnicity, region of the United States, percentage of the poverty threshold, education, exercise, and smoking status.
2. Based on food only; all beverages were excluded.
3. ANOVA was used for each sex to compare persons within the 3 categories of energy density; for each sex, mean values with different superscript letters are significantly different, *P* < 0.05.
4. Tap and bottled water were excluded.
in fruit and vegetables (>9 servings/d) consumed a lower percentage of energy from saturated fat (data not shown).

In both categories of fat intake, persons consuming the most servings of fruit and vegetables had the lowest dietary energy density values. Overall, those who consumed a low-fat diet (≤30% of energy from fat) that was rich in fruit and vegetables (>9 servings/d) had diets with the lowest energy density; they were followed by those with a high-fat diet that was rich in fruit and vegetables (>9 servings/d). Dietary energy density was lower for persons with a high-fat diet and a high consumption of fruit and vegetables than for persons with a low-fat diet and a low consumption of fruit and vegetables.

Persons with a high-fat diet and a low intake of fruit and vegetables (<5servings/d) had the highest prevalence of obesity (Figure 3). Within both of the fat intake categories, the prevalence of obesity was lowest for persons with a diet high in fruit and vegetables (9% in the high-fat group and 6% in the low-fat group).

### DISCUSSION

Drawing on a representative sample of US adults, we found that those whose diet had a low energy density had the lowest total intakes of energy, even though they consumed the greatest amount of food by weight. This study builds on laboratory-based studies indicating that reductions in the energy density of the diet are associated with decreased energy intake (4–9) and provides ecological validity for the hypothesis that consumption of a low-energy-dense diet is associated with reduced energy intake.

Studies in free-living Mediterranean (21), Chinese (22), and French (23) also found that those with a diet low in energy density consumed less energy. The finding in the present study that persons with a low-energy-dense diet consumed the greatest amount of food has important implications for promoting compliance with prescribed dietary regimens. A diet plan that severely restricts the amount of food a patient consumes will likely lead to feelings of hunger and have unfavorable influences on the patient’s satisfaction with the diet and long-term compliance. Positive messages that encourage people to eat certain foods, such as fruit and vegetables, have been found to be more effective for weight management than messages that restrict certain foods (24).

Although it is important to understand the relation between energy density and food intake, it is also critical to explore the relation between energy density and body weight. In the present study, those who were obese consumed diets higher in energy density than did those who were not obese. Although several studies in the literature have found lower dietary energy density values to be associated with a more favorable body weight (25–27), other studies have not supported such a relation (21, 23, 28). One potential explanation for the inconsistent findings may be that different schemes for including beverages in the calculation of energy density were used in these studies. Beverages tend to have a lower energy density than do most foods and may disproportionately influence dietary energy density values (20). Furthermore, data indicate that including beverages as part of the diet when calculating dietary energy density may weaken associations with weight status because of increased within-person variance (20). The lack of an association between body weight and dietary intake in some studies may be due to the cross-sectional
FIGURE 2. Energy density of food patterns characterized by different intakes of fat and of fruit and vegetables. Juice and fried or dried fruit and vegetables were excluded. There was a significant interaction between intakes of fat and of fruit and vegetables ($P < 0.05$). ANOVA was used to test for differences in dietary energy density by each of the 6 food patterns. Values were adjusted for age group, race-ethnicity, region of the United States, percentage of the poverty threshold, education, exercise, and smoking status. Bars with different lowercase letters are significantly different, $P < 0.05$. Error bars represent SEs.

**Fruit and vegetable intake (servings/d)**

- High fat (>30% of energy)
  - 2.07 (n=4186)
  - 1.64 (n=850)
  - 1.41 (n=140)
  - 1.78 (n=1600)
  - 1.42 (n=483)
  - 1.22 (n=97)

- Low fat (≤30% of energy)

FIGURE 3. Prevalence of obesity [BMI (in kg/m²) ≥ 30] in persons with food patterns characterized by different intakes of fat and of fruit and vegetables. Juice and fried or dried fruit and vegetables were excluded. There was a significant interaction between intakes of fat and of fruit and vegetables ($P < 0.05$). A chi-square test was used to test for differences in obesity prevalence by each of the 6 food patterns. Bars with different lowercase letters are significantly different, $P < 0.05$. Error bars represent SEs.

**Fruit and vegetable intake (servings/d)**

- High fat (>30% of energy)
  - 18 (n=4186)
  - 17 (n=850)
  - 14 (n=140)
  - 13 (n=1600)
  - 13 (n=483)
  - 6 (n=97)

- Low fat (≤30% of energy)
nature of these studies if the participants did not have a stable body weight. Another potential explanation for the conflicting results in the literature is the degree to which the studies accounted for confounding variables. Stookey (22) reported that the relation between energy density and weight status was strengthened by adjustments for covariates. The present study included potential covariates, but physical activity was assessed with only one question that pertained to the frequency of vigorous exercise, which may not have been sufficient. Care should be taken in future studies to fully assess and control for possible confounding variables.

A strength of this article is that it not only examined the relation between energy density and weight status but also explored how these findings can be put into a practical context for dietary advice. These data indicate that a diet that has a low energy density does not have to be low in fat if it is rich in fruit and vegetables. Consumption of ≥9 servings of fruit and vegetables was associated with lower dietary energy density values as well as a lower prevalence of obesity even for diets high in fat. Although evidence in the literature showing a relation between intake of fruit and vegetables and body weight is limited, these findings support a recent review of epidemiologic studies that found a tendency for higher body weights to be associated with lower consumption of fruit and vegetables (15).

A limitation of this study is the use of self-reported measures of body weight. Data indicate that overweight persons are not only likely to underreport anthropometric measures (29) but are also likely to misreport food intakes (30, 31). Consistent underreporting or overreporting across all types of foods will likely have little influence on energy density values. However, data indicate that overweight persons may selectively underreport intakes of high-fat foods (32, 33), which could cause energy density estimations to be lower than actual values. Further work is needed to understand the potential influence of misreporting on estimated energy density values (20) as well as the consequences of shared error bias between anthropometric and dietary measures in epidemiologic studies (32). In the present study, however, the potential shared error created by underreporting of dietary measures by obese persons would likely have weakened associations between energy density and weight status and possibly led to a null finding.

Dried and fried fruit and vegetables and juices were not included when determining fruit and vegetable servings, because a recent review article (15) emphasizes the importance of attention to food preparation methods when investigating associations between food intake and body weight. Note, however, that current dietary guidelines include these items as fruit and vegetables (1). Additionally, because of the cross-sectional design of this study, inferences regarding cause and effect are limited. These data are, however, supported by findings from laboratory and clinical studies.

Behavioral changes that yield modest but persistent reductions in energy intake are likely to be critical to successful weight loss. Decreasing overall food intake as a strategy to reduce energy intake is unlikely to be successful in the current eating environment, ie, one in which large portions of energy-dense foods are common. It is preferable to make subtle changes to reduce the energy density of the diet, which will result in long-term acceptance. For example, the energy density of many popular foods, such as pizza, sandwiches, and casseroles, can be decreased by reducing the fat content and through the addition of water-rich vegetables without necessarily affecting palatability or portion size (13). Furthermore, selecting foods on the basis of a low energy density can lead to healthy food patterns, such as those consistent with the Dietary Guidelines for Americans (1) and the new MyPyramid food guidance system (18).

The energy density of a variety of different dietary patterns can be lowered, even those that are high in fat. Although a simultaneous decrease in fat intake and an increase in fruit and vegetable intake will likely have the greatest effect on energy density and body weight, this approach may not be best for all patients, particularly those unwilling to consume a low-fat diet. Because palatability and food preferences play a critical role in food selection (34), structuring dietary advice around a patient’s existing dietary pattern to achieve a reduction in energy density may increase the likelihood that long-lasting dietary changes will be achieved.

All authors participated equally in the conception, design, and interpretation of these analyses and in the revision of the text. JHL conducted the analyses and wrote the first draft of the manuscript. None of the authors had any financial or personal interest with the funding agency or any other agency related to the topic of this article.

REFERENCES

14. Rolls BJ, Ello-Martin JA, Tohill BC. What can intervention studies tell...


