Low energy density and high nutritional quality are each associated with higher diet costs in French adults\textsuperscript{1–3}

Matthieu Maillot, Nicole Darmon, Florent Vieux, and Adam Drewnowski

ABSTRACT

Background: Low-energy-density diets are associated with higher diet costs per 10 MJ. Are diets of higher nutritional quality also associated with higher costs per 10 MJ?

Objective: The objective was to determine the relations between energy-adjusted diet costs, dietary energy density, and nutritional quality of diets.

Design: This was a cross-sectional study of a nationally representative sample of 1332 French adults in the 1999 Enquête Individuelle et Nationale sur les Consommations Alimentaires (INCA) data set. Analyses were based on data from 7-d food records. The monetary cost of each diet was estimated by using mean retail prices for 620 foods. Nutritional quality was estimated by calculating the mean adequacy ratio (MAR), based on 23 nutrients. Energy density was based on solid foods only.

Results: In a bivariate analysis, low-energy-density diets were of higher nutritional quality but also cost more. Participants in the highest tertile of MARs had the lowest dietary energy density and the highest diet costs, calculated both per day and per 10 MJ. In a multivariate model, dietary energy density was negatively linked to diet costs (€/10 MJ), whereas MAR values were positively linked to diet costs after adjustment for age and energy intake. For a given energy intake and energy density, each 10\% increase in MAR led to a 13\% increase in estimated diet costs per 10 MJ.

Conclusions: In this study of self-selected diets of French adults, lower energy density and higher nutritional quality were associated with higher energy-adjusted diet costs. Higher-quality diets cost more not only because they have a low energy density but also because they are nutrient rich.  


KEY WORDS
Dietary energy density, nutritional quality, mean adequacy ratio, diet cost

INTRODUCTION

Food choices are influenced by taste, convenience, concerns with nutrition and body weight, and food costs (1, 2). Limited budgets (3–5) may help explain why the consumption of vegetables and fruit known to be associated with dietary quality is strongly and inversely linked to indexes of socioeconomic status (6–10). If higher-quality diets also cost more (11, 12), then the ability to adopt healthier diets may be an economic and a behavioral challenge (13–15).

To reduce dietary energy density, individuals are encouraged to select diets that are high in lean meats, low-fat dairy products, and fresh vegetables and fruit (16). However, lower-energy-density diets were associated in past studies with higher monetary costs, after adjustment for energy intakes (17–20). This may be because the more nutrient-dense foods are expensive sources of dietary energy, whereas added sugars and fats typically are not (15).

Low-energy-density diets tend to have a higher nutrient content than do energy-dense diets (21, 22). In past studies, the highest diet costs were associated with the consumption of antioxidant phytonutrients found in vegetables and fruit (23). This study examined the relations between estimated diet costs per 10 MJ, energy density, and nutritional quality. The latter was assessed by using a previously described global index of nutrient adequacy—the mean adequacy ratio (MAR) (24). The hypothesis was that both dietary energy density and nutrient content are each independent predictors of diet cost at a given dietary energy.

SUBJECTS AND METHODS

Study population

The study was based on a dietary survey of a nationally representative sample of 1985 French adults aged 15–92 y that was conducted in 1999 by the French National Agency for Food Safety. Quota sampling was used to ensure that the demographic makeup of the study sample corresponded to that of the French population. All participants completed 7-d food records, aided by a photographic manual of portion sizes (25). After under- and overreporters were excluded by using standard procedures (26), dietary data for 1332 participants (596 men and 736 women) were available for analysis.

Alcoholic beverages, tea, coffee, and drinking water were excluded from all analyses because their consumption is generally not well reported in epidemiologic studies and also because the variability in prices is very high for these beverages.

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2 MM was supported by the French National Research Agency’s 2005-2008 “Nutritional Policies” project, and AD was supported by the National Research Initiative of the USDA Cooperative State Research Education and Extension Service grant 2004-35215-14441.

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TABLE 1
Recommended Dietary Allowances (RDA), median nutrient intakes, and mean adequacy ratio (MAR) in men and women in the INCA study.

<table>
<thead>
<tr>
<th>Nutrients</th>
<th>RDA</th>
<th>Median</th>
<th>SD</th>
<th>RDA</th>
<th>Median</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men (n = 596)</td>
<td></td>
<td></td>
<td></td>
<td>Women (n = 736)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proteins (g/d)</td>
<td>70</td>
<td>106</td>
<td>24</td>
<td>50</td>
<td>80</td>
<td>19</td>
</tr>
<tr>
<td>Fiber (g/d)</td>
<td>30</td>
<td>19</td>
<td>6.4</td>
<td>30</td>
<td>16</td>
<td>5.1</td>
</tr>
<tr>
<td>Linoleic acid (g/d)</td>
<td>10</td>
<td>11</td>
<td>4.1</td>
<td>8.0</td>
<td>9.2</td>
<td>3.6</td>
</tr>
<tr>
<td>Linolenic acid (g/d)</td>
<td>2.0</td>
<td>0.9</td>
<td>0.5</td>
<td>1.6</td>
<td>0.7</td>
<td>0.3</td>
</tr>
<tr>
<td>DHA (g/d)</td>
<td>0.12</td>
<td>0.13</td>
<td>0.2</td>
<td>0.10</td>
<td>0.10</td>
<td>0.2</td>
</tr>
<tr>
<td>Vitamin A (µg/d)</td>
<td>800</td>
<td>1290</td>
<td>1074</td>
<td>600</td>
<td>1078</td>
<td>927</td>
</tr>
<tr>
<td>Thiamine (mg/d)</td>
<td>1.3</td>
<td>1.3</td>
<td>0.4</td>
<td>1.1</td>
<td>1.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Riboflavin (mg/d)</td>
<td>1.6</td>
<td>1.7</td>
<td>0.5</td>
<td>1.5</td>
<td>1.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Niacin (mg/d)</td>
<td>14</td>
<td>19</td>
<td>5.3</td>
<td>11</td>
<td>14</td>
<td>4.4</td>
</tr>
<tr>
<td>Vitamin B-6 (mg/d)</td>
<td>1.8</td>
<td>1.9</td>
<td>0.5</td>
<td>1.5</td>
<td>1.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Folates (µg/d)</td>
<td>330</td>
<td>303</td>
<td>90</td>
<td>300</td>
<td>254</td>
<td>80</td>
</tr>
<tr>
<td>Vitamin B-12 (µg/d)</td>
<td>2.4</td>
<td>6.3</td>
<td>4.8</td>
<td>2.4</td>
<td>4.8</td>
<td>4.1</td>
</tr>
<tr>
<td>Ascorbic acid (mg/d)</td>
<td>110</td>
<td>73</td>
<td>63</td>
<td>110</td>
<td>77</td>
<td>54</td>
</tr>
<tr>
<td>Vitamin E (mg/d)</td>
<td>12</td>
<td>12.6</td>
<td>4.7</td>
<td>12</td>
<td>11.0</td>
<td>4.6</td>
</tr>
<tr>
<td>Vitamin D (µg/d)</td>
<td>5.0</td>
<td>1.8</td>
<td>1.6</td>
<td>5.0</td>
<td>1.4</td>
<td>1.6</td>
</tr>
<tr>
<td>Calcium (mg/d)</td>
<td>900</td>
<td>795</td>
<td>313</td>
<td>900</td>
<td>727</td>
<td>254</td>
</tr>
<tr>
<td>Potassium (mg/d)</td>
<td>3100</td>
<td>2735</td>
<td>609</td>
<td>3100</td>
<td>2341</td>
<td>554</td>
</tr>
<tr>
<td>Iron (mg/d)</td>
<td>9.0</td>
<td>13</td>
<td>3.3</td>
<td>16.0</td>
<td>10</td>
<td>2.8</td>
</tr>
<tr>
<td>Magnesium (mg/d)</td>
<td>420</td>
<td>257</td>
<td>56</td>
<td>360</td>
<td>211</td>
<td>48</td>
</tr>
<tr>
<td>Zinc (mg/d)</td>
<td>12</td>
<td>12.7</td>
<td>3.6</td>
<td>10</td>
<td>9.7</td>
<td>2.8</td>
</tr>
<tr>
<td>Copper (mg/d)</td>
<td>2.0</td>
<td>1.3</td>
<td>0.6</td>
<td>1.5</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Iodine (mg/d)</td>
<td>150</td>
<td>128</td>
<td>48</td>
<td>150</td>
<td>111</td>
<td>40</td>
</tr>
<tr>
<td>Selenium (µg/d)</td>
<td>60</td>
<td>66</td>
<td>23</td>
<td>50</td>
<td>51</td>
<td>19</td>
</tr>
<tr>
<td>MAR (% adequacy/d)</td>
<td>84.4</td>
<td>7.8</td>
<td></td>
<td>79.9</td>
<td>8.9</td>
<td></td>
</tr>
</tbody>
</table>

1 INCA, Enquête Individuelle et Nationale sur les Consommations Alimentaires; DHA, docosahexaenoic acid.
2 Significantly different from the RDA, P < 0.05 (univariate sign test).
3 Significantly different from 100%, P < 0.05 (univariate sign test).

Dietary energy density

Daily food weights (FIi; in kg/d) and daily energy intakes (EIi; in MJ/d) were calculated for each individual (i) by summing the edible weight and the energy content of all foods consumed daily and dividing by the number of days of data collected for that person. Calculations of dietary energy density were based on “food only” as described by Ledikwe et al (27). Only items typically consumed as foods, including soups, were included in the calculation, whereas items consumed as beverages, such as milk, juices, and soft drinks, were excluded. Energy density (EDi; in MJ/kg) was calculated by dividing daily energy intakes provided by foods (EIFi) by the daily weights of foods (FIFi) as follows:

$$ED_i = \frac{EIF_i}{FIF_i}$$  (1)

Additional calculations of energy density were based on foods and calorie-containing beverages only (including milk, juices, and soft drinks) but excluding noncalorie-containing beverages and drinking water. Procedures used to determine energy density were reported previously (27).

Nutritional quality measure

MARi was used as an indicator of nutritional quality. The MAR was initially described as a truncated index of the percent of daily recommended intakes for 8 nutrients, including energy and protein (24, 28). The MAR has been used to estimate the nutrient adequacy of the total diet (29). Although multiple versions of this index exist, MAR has been repeatedly shown to be positively associated with other indexes of diet quality, notably those estimating dietary diversity or variety (28, 30–34). Positive relations with health indicators have been also reported (35, 36). Following earlier models, the present version of the MAR was not weighted to reflect the differential importance of different nutrients, and no attempt was made to correct for the bioavailability of a given nutrient when present in different food sources. All the nutrients available in our food-composition database were included in the MAR score. The present adaptation of MAR was based on the mean percentage of the recommended intakes for 23 key nutrients and was calculated as follows:

$$MAR_i = \frac{100}{23} \times \sum_{p=1}^{23} \left( \frac{\text{Intake}_{ip}/\text{RDA}_{ip}}{} \right)$$  (2)

where Intake_{ip} is the daily intake of each nutrient p, and RDA_{ip} is the French Recommended Dietary Allowance (37) for that nutrient. As in past studies, each ratio (Intake_{ip}/RDA_{ip}) was truncated at 1, so that a high intake of one nutrient could not compensate for the low intake of another nutrient (24). The list and reference values for the 23 recommended nutrients are given in Table 1. Unlike energy density, MAR was calculated for the whole diet (including milk, juice, and soft drinks) but excluding alcoholic beverages, tea, coffee, and drinking water.
Estimated diet costs

The food-composition database, developed for the Enquête Individuelle et Nationale sur les Consommations Alimentaires (INCA) (38) and SU.VI.MAX (39) studies, was supplemented with other data (40–42), including the USDA food-composition data (43) for zinc, copper, iodine, and selenium. The food price vector paralleled the nutrient composition vectors. Food prices were based on the mean 1997 retail prices in France, as obtained from marketing research (SECODIP), from the French National Institute of Statistics (INSEE), and from supermarket websites. Because these were the prices paid by a representative panel of French consumers (SECODIP), the mean price reflected the most frequently purchased forms of each food. After adjustment for preparation and waste, food costs were expressed in euros per 100 g edible portion. Diet costs per day (€/d) were then estimated by multiplying the reported edible weight of each food by its unit cost and summing over all foods consumed by that individual. Unlike energy density, diet cost was calculated for the whole diet by multiplying the reported edible weight of each food by its unit cost. Diet costs per day (€/d) and per 10 MJ (€/10 MJ) were also calculated.

Statistical analyses

The relations between dietary energy density, MAR, and estimated diet costs were analyzed separately for men and women. First, the strength of the association was tested by using both simple and partial Pearson’s correlation coefficients with adjustment for energy intake. Second, general linear model (GLM) analysis was used to compare the means of each variable within tertiles of the other variables, after adjustment for age and energy intake. Third, potential predictors of diet cost per 10 MJ were tested by using multivariate linear regression models. Because the risk of multicolinearity of independent variables with energy intake was high, we also tested the same multivariate models by using the residual method proposed by Willett and Stampfer (44). All analyses were stratified by sex. Median intakes of nutrients and of MAR were compared with their corresponding recommended values with the univariate sign test. An α level of 0.05 was used to determine statistical significance. Statistical analyses were performed by using SAS software version 9.1 (SAS Institute, Cary, NC).

RESULTS

Participant characteristics

Mean (±SD) age was 43.7 ± 17.6 y for men and 43.0 ± 17.7 y for women (Table 2). Estimated daily diet costs were higher for men (5.26 €/d) than for women (4.26 €/d). The mean estimated cost (4.71 €/d) was similar to the French national estimates of expenditures for food, with the exclusion of restaurants and alcoholic drinks (ie, 4.85 €/d) (45).

Men had higher energy intakes and consumed diets of higher energy density than did women. However, dietary energy costs were lower in men than in women (5.35 compared with 5.51 €/10 MJ). MAR values were 84.4 ± 7.8% for men and 79.9 ± 8.9% for women, which indicated that the diets met, on average, 84% and 80% of the RDA value for the 23 nutrients included in the MAR score (Table 1).

Energy density and nutritional quality

The crude and energy-adjusted correlation coefficients between dietary energy density, nutritional quality, and estimated diet cost per 10 MJ are shown in Table 3. The directions of the associations were the same with and without energy adjustment. Low energy density was associated with higher MAR scores (men: −0.55; women: −0.59) after energy adjustment. Low energy density was associated with higher estimated diet costs per 10 MJ (men: −0.52; women: −0.49) after energy adjustment. High nutritional quality, as indexed by MAR scores, was also associated with higher diet costs per 10 MJ (men: 0.58; women: 0.58) after energy adjustment. As expected (data not shown), in bivariate analysis, higher dietary energy density was positively associated with energy intake (r = 0.36, P < 0.0001). Participants in the highest tertile of nutritional quality had the lowest energy density and the highest diet costs, calculated both per day and per 10 MJ (Table 4). GLM analysis confirmed that a reduction in dietary energy density was associated with an increase in nutritional quality as well as an increase in estimated diet costs. This relation held for both men and women after adjustment for age and energy intake (Figure 1).

A multivariate linear model was used to estimate the independent effects of low energy density and high nutritional quality on

### TABLE 2

Daily energy intake, energy density, diet cost per day, and age of men and women participating in the INCA study<sup>1</sup>

<table>
<thead>
<tr>
<th></th>
<th>Men (n = 596)</th>
<th>Women (n = 736)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>43.7 ± 17.6</td>
<td>43.0 ± 17.7</td>
</tr>
<tr>
<td>Daily energy intake (MJ/d)</td>
<td>9.92 ± 1.99</td>
<td>7.80 ± 1.53&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Energy density (MJ/kg)</td>
<td>7.31 ± 122</td>
<td>6.78 ± 1.12&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Diet cost per day (€/d)</td>
<td>5.26 ± 1.24</td>
<td>4.26 ± 1.01&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Diet cost per 10 MJ (€/10 MJ)</td>
<td>5.35 ± 0.99</td>
<td>5.51 ± 1.02&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup> All values are x ± SD. INCA, Enquête Individuelle et Nationale sur les Consommations Alimentaires.

<sup>2</sup> Significantly different from men, P < 0.05 (Student’s t test).

### TABLE 3

Simple and partial Pearson correlations between dietary energy density, diet cost, and the nutritional quality measure [mean adequacy ratio (MAR)] in men and women in the INCA study<sup>1</sup>

<table>
<thead>
<tr>
<th></th>
<th>Men (n = 596)</th>
<th>Women (n = 736)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy density (MJ/kg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diet cost (€/10 MJ)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy-adjusted</td>
<td>−0.55&lt;sup&gt;2&lt;/sup&gt;</td>
<td>−0.51&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Not adjusted</td>
<td>−0.52&lt;sup&gt;2&lt;/sup&gt;</td>
<td>−0.49&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Nutritional quality (MAR)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy-adjusted</td>
<td>0.29&lt;sup&gt;2&lt;/sup&gt;</td>
<td>−0.16&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Not adjusted</td>
<td>0.58&lt;sup&gt;2&lt;/sup&gt;</td>
<td>−0.55&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup> INCA, Enquête Individuelle et Nationale sur les Consommations Alimentaires.

<sup>2</sup> Significantly different from 0, P < 0.001.
diet costs per 10 MJ (Table 5). Models 1 and 2 confirmed that energy density was negatively associated with diet cost per 10 MJ, whereas MAR scores were positively associated with diet cost per 10 MJ. These relations persisted when both variables were entered into model 3. In this model, the unadjusted β coefficients for MAR values were 0.070 in men and 0.072 in women. A 10% increase in MAR values (from 80% to 90% for instance), at constant energy density and energy intake levels, would therefore lead to an increase in diet costs equal to 0.70 €/10 MJ in men and 0.72 €/10 MJ in women. That is equivalent to a 13% increase in diet costs per 10 MJ. In model 3, the standardized β for MAR was higher than that for energy density. This showed that nutrient adequacy, as indexed by MAR scores, was not only an independent predictor of diet costs per 10 MJ, but was a stronger predictor of diet cost than was energy density. In multivariate analysis, energy intake was negatively associated with diet cost per 10 MJ.

These data indicate that individuals with lower energy density and higher nutritional quality diets had higher diet costs per 10 MJ, despite lower energy intakes. The findings were unchanged when we used residuals of independent variables instead of the crude variables, according to Willett and Stampfer (44).

On average, dietary energy provided by fluid milk, juices, and soft drinks represented 5% of total energy intake (and 4% of total daily cost), ≈3–4 times lower than the corresponding value for the United States in 2001 (46). The inclusion of calorie-containing beverages in the energy density calculation had a minimal effect on the present results. The only difference was that the inverse association found between energy density and energy diet cost per 10 MJ in the multivariate model 3 (Table 5) lost statistical significance in women (but not in men) when the calculation of energy density included milk, juices, and soft drinks (β = −0.020, P = 0.5402; data not shown).

**DISCUSSION**

Dietary energy density and the nutritional quality of the diet were each independent predictors of estimated diet cost, calculated per 10 MJ. Whereas the more energy-dense diets cost less, the more nutrient-dense diets were found to cost more. These associations were independent of each other and were not influenced by age, sex, or energy intakes.

A reduction in the energy density of the diet is one strategy to stem the obesity epidemic (16). This can be accomplished in practice by decreasing the consumption of dietary fat or by increasing the consumption of vegetables and fruit (47). However, diets high in vegetables and fruit were found to cost more per MJ than did diets that were high in fats and sweets (19, 20). The cost

![FIGURE 1. Nutritional quality, estimated by calculating the mean adequacy ratio (MAR), and diet cost, adjusted for energy intake and age, in each tertile of energy density (MJ/kg) in men and women in the Enquête Individuelle et Nationale sur les Consommations Alimentaires (INCA) study. Bars represent the 95% CI. The decreasing trend of nutritional quality by tertile of energy density was significant (P < 0.05) in men and women. The decreasing trend of diet cost by tertile of energy density was significant (P < 0.05) in men and women.](https://academic.oup.com/ajcn/article-abstract/86/3/690/4649217)
TABLE 5
Partial correlation coefficients (β) of multivariate linear regression models with diet cost (per 10 MJ) as the dependent variable and energy density (MJ/kg), nutritional quality, mean adequacy ratio (MAR), or both as independent variables, adjusted for energy intake and age in men and women in the INCA study.

<table>
<thead>
<tr>
<th>Model</th>
<th>Men (n = 596)</th>
<th>Women (n = 736)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>β (SD)</td>
<td>Standardized β</td>
</tr>
<tr>
<td>Intercept</td>
<td>8.733 (7.356)</td>
<td>0</td>
</tr>
<tr>
<td>Energy density (MJ/kg)</td>
<td>-0.446 (0.776)</td>
<td>-0.547</td>
</tr>
<tr>
<td>Energy intake (MJ/d)</td>
<td>-0.012 (0.440)</td>
<td>-0.025</td>
</tr>
<tr>
<td>Age (y)</td>
<td>-0.0001 (0.051)</td>
<td>-0.052</td>
</tr>
<tr>
<td>Intercept</td>
<td>0.538 (8.801)</td>
<td>0</td>
</tr>
<tr>
<td>MAR (%)</td>
<td>0.094 (0.134)</td>
<td>0.738</td>
</tr>
<tr>
<td>Energy intake (MJ/d)</td>
<td>-0.333 (0.536)</td>
<td>-0.669</td>
</tr>
<tr>
<td>Age (y)</td>
<td>0.007 (0.046)</td>
<td>0.124</td>
</tr>
<tr>
<td>Intercept</td>
<td>4.439 (13.478)</td>
<td>0</td>
</tr>
<tr>
<td>Energy density (MJ/kg)</td>
<td>-0.235 (0.847)</td>
<td>-0.288</td>
</tr>
<tr>
<td>MAR (%)</td>
<td>0.070 (0.155)</td>
<td>0.552</td>
</tr>
<tr>
<td>Energy intake (MJ/d)</td>
<td>-0.233 (0.631)</td>
<td>-0.467</td>
</tr>
<tr>
<td>Age (y)</td>
<td>0.002 (0.045)</td>
<td>0.066</td>
</tr>
</tbody>
</table>

1 INCA, Enquête Individuelle et Nationale sur les Consommations Alimentaires. The interaction between sex and MAR score was significant; hence, the data for men and women were analyzed separately.
2 R² = 30.8% for men and 27.6% for women.
3 R² = 38.2% for both men and women.
4 R² = 42.6% for men and 40.4% for women.

Differential was attributed to the high water content and very low energy density of vegetables and fruit (48). Another strategy for a healthier diet is to replace refined grains, fatty meats, and full-fat dairy products with more nutrient-dense options (16, 47, 49). Replacing energy-rich foods with more nutrient-dense equivalents will have the desired effect of lowering dietary energy density, increasing nutrient intakes, or both. However, some of these substitution strategies have also been shown to result in higher diet costs (17, 50). The present analyses indicate one reason for this observation: reductions in energy density and increases in nutrient density were each independently associated with higher diet costs.

Arguably, not all high-quality diets are inevitably associated with higher diet costs. There are numerous examples, notably the US Department of Agriculture (USDA) Thrifty Food Plan (51), showing that nutritionally adequate diets can be obtained at minimum cost (52–56). However, USDA researchers themselves have acknowledged that the suggested recipes fell short when it came to variety, enjoyment, and convenience (57). In other cases, food patterns of specific immigrant and ethnic groups have been identified as “healthy” (58). However, such diets often deviate considerably from the typical food habits of the general population (59) and may not be acceptable to the majority of consumers. In other words, high-quality diets need not cost more, but, on the basis of a large sample of self-selected diets, they do under normal circumstances (17–20, 23, 60).

Some limitations of the present study must be noted. One limitation was that the cost of dietary energy was estimated from the unit price of each food, adjusted for preparation and waste. However, the use of food prices to estimate the monetary cost of each diet is a relatively common approach (12, 18, 23, 61, 62). In the absence of food expenditure data, the Economic Research Service of the USDA used national food prices to devise the Thrifty Food Plan, a model of a low-cost but optimally nutritious diet (51). The present prices reflected the price of foods as typically purchased by the French population. For example, the price of green beans was mainly based on the canned rather than the fresh product, because that is how beans are purchased by the typical French consumer. This led to realistic estimates of diet costs, as shown by the similarity with the French national estimates of expenditures for food (45).

Dietary energy density is mainly driven by the water content of foods and beverages (63, 64). Energy density values can vary widely, depending on whether water and noncalorie-containing and calorie-containing beverages have been included or excluded from analysis (27, 65). On the basis of past research (27), we based the present calculations on foods only, largely because energy density of the solid part of the diet is reported to be a better indicator of dietary quality than is energy density based on food and energy-yielding beverages (21). This is probably explained by the large within-person variation relative to between-person variation that occurs for energy density when all calorie-containing beverages are included in the analysis (27), which attenuates its association with outcome variables. Accordingly, in the present study, including milk, juices and soft drinks in the calculation of energy density, attenuated its relation with energy cost in multivariate models.

In addition, individuals drinking primarily water have relatively high energy density values when calorie-containing beverages are included, although they are likely to have diets of better quality than are individuals drinking primarily calorie-containing beverages (21, 22). Thus, absolute nutrient intakes,
calculated for both foods and beverages, were found to be greater for subjects with a low-energy-density diet, calculated for foods only (21, 66). Likewise, in the present study, low energy density, calculated for foods only, was associated with higher MAR scores, calculated for both foods and beverages.

The higher cost of healthier diets may help explain the often-reported association between higher diet quality and better health. In a number of studies, the consumption of higher quality—and very likely, more costly—dias has been associated with higher BMI values and increased chronic disease risk (16, 71). Encouraging participants to adopt healthier lifestyles may not be effective if the higher cost of healthier diets represents a barrier to dietary change (59, 61, 72, 73). If the more nutrient-dense diets are necessarily more expensive, then the current attempts to improve diet quality of the population need to take economic issues into account. It is not a coincidence that diet-related diseases, including obesity, type 2 diabetes, the metabolic syndrome, and cardiovascular disease risk, all seem to represent a barrier to dietary change (59, 61, 72, 73). If the more nutrient-dense diets are necessarily more expensive, then the current attempts to improve diet quality of the population need to take economic issues into account. It is not a coincidence that diet-related diseases, including obesity, type 2 diabetes, the metabolic syndrome, and cardiovascular disease risk, all seem to follow a strong socioeconomic gradient (74).

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