simple changes within dietary subgroups can rapidly improve the nutrient adequacy of the diet of French adults

Eric O. Verger, Bridget A. Holmes, Jean François Huneau, and François Mariotti

Abstract

Identifying the dietary changes with the greatest potential for improving diet quality is critical to designing efficient nutrition communication campaigns. Our objective was to simulate the effects of different types of dietary substitutions to improve diet quality at the individual level. Starting from the observed diets of 1330 adults participating in the national French Nutrition and Health Survey (Étude Nationale Nutrition Santé), we simulated the effects of 3 different types of food and beverage substitutions with graded implementation difficulty for the consumer in a stepwise dietary counseling model based on the improvement in the PANDiet index, which measures diet quality in terms of nutrient adequacy. In scenario 1, substitutions of a food or beverage for its “lighter” version resulted in a modest improvement in the PANDiet score (Δ = +3.3 ± 0.1) and a decrease in energy intake (Δ = −114 ± 2 kcal/d). In scenario 2, substitutions of a food or beverage within the same food subgroup resulted in a marked improvement in the PANDiet score (Δ = +26.4 ± 0.2) with no significant change in energy intake. In this second scenario, the improvement in nutrient adequacy was due to substitutions in many subgroups, with no single subgroup contributing >8% to the increase in the PANDiet score. In scenario 3, substitutions of a food or beverage within the same food group resulted in the greatest improvement in the PANDiet score (Δ = +31.8 ± 0.2) but with an increase in energy intake (Δ = +204 ± 9 kcal/d). In this third scenario, the improvement in nutrient adequacy was largely due to substitutions of fish for meat and processed meat (~30% of the increase in the PANDiet score). This study shows that a strategy based on simple substitutions within food subgroups is effective in rapidly improving the nutritional adequacy of the diet of French adults and could be used in public health nutrition actions.

Introduction

National dietary guidelines typically consist of a series of recommendations that aim to improve dietary intakes and positively influence health-related outcomes (1–3). Research has demonstrated that a considerable proportion of any given population may fail to reach all or some of these recommendations. For example, 82% and 87% of American adults do not meet the U.S. recommendations for fruit and vegetable intakes, respectively (4), and 55% of French adults do not meet the French recommendation for fruit and vegetables (5). In both populations, major barriers to eating a healthy diet were related to the lack of knowledge regarding the recommendations and their health benefits and difficulties in changing eating habits (6,7).

Identifying which dietary changes have the greatest potential for improving diet quality is critical to designing efficient public health nutrition actions (8). To date, 2 main approaches have been used for evaluating the potential for improving diet. The first approach involves simulating the impact of replacing foods and beverages with a priori healthier alternatives: for example, substituting sugar-sweetened beverages for water and observing the impact on total energy intake (9–11); substituting canola oil for soybean, corn, cottonseed, safflower, or sunflower oils and observing the impact on intake of FAs (12); or substituting several different food and beverages and observing the impact on diet quality and energy intake (13). The second approach involves using a mathematical optimization technique known as linear programming to identify and quantify dietary changes needed to achieve nutritional recommendations at the population level (14). In contrast to the former approach, this latter approach rigorously converts nutrient constraints into food combinations without using any a priori judgment about the nutritional quality of a given food (15).
One drawback of this second approach is that the outputs obtained are often not translatable into dietary recommendations because of impractical portion sizes (16). Furthermore, this approach provides an entirely optimized diet, with little indication of the improvement made in diet quality as a result of each change, and little indication of the approach to progressively apply these changes to reach the optimized diet. Simulating the effects of a stepwise dietary counseling approach would help to identify the most efficient pathway for dietary improvement in a population and may ultimately increase the likelihood of adoption and success. The objective of the present study was therefore to simulate the effects of 3 different types of food and beverage substitutions at the individual level, with an increasing level of difficulty for the consumer, and to compare the improvement in the diet quality of French adults.

Participants and Methods

Dietary data

Dietary data used in this study came from a descriptive cross-sectional survey undertaken in 2006 in a randomly selected national sample of noninstitutionalized adults, 18–74 y of age, living in mainland France: the French Nutrition and Health Survey [Etude Nationale Nutrition Santé (ENNS)] (17). Dietary data were collected by using three 24-h recalls with dates randomly selected within a 2-wk period. Nutritional values for energy and nutrients were obtained from a previously published nutrient database (18), which was updated to include recently marketed foods and recipes. Mean individual intakes of food and nutrients were calculated, and a weighting for the day of the week (5/7 for a weekday and 2/7 for a weekend day) was applied. The survey protocol received the approval of the Ethical Committee (Hôpital Cochin, Paris, no. 2264), the Consultative Committee on Information Treatment of the Ministry of Research, and the French Data Protection Authority (Commission Nationale de l’Informatique et des Libertés, authorization no. 905481).

Of those participants who completed the survey (n = 3115), we excluded those who did not provide three 24-h recalls, those who had incomplete data required to calculate the measurement of diet quality (PANDiet), those who were pregnant or lactating, or those who were identified as over- or underreporters on the basis of the method proposed by Black (19). This resulted in a final number of 1330 participants (i.e., 43% of those who completed the survey).

Nutrient adequacy

The diet quality of each individual was calculated by using the PANDiet index, which measures diet quality in terms of nutrient adequacy. Its content and construct validity have been fully described previously (20). Briefly, we calculated the probability of adequacy for each available nutrient, ranging from 0 to 1, where 1 represents a 100% probability that the intake is adequate according to a reference value. The calculation of the probability takes into account the number of days of dietary data, the mean intake and the day-to-day variability in intake, the nutrient reference value, and interindividual variability. We assessed separately the probability that the intake was adequate because it satisfied the requirement as well as the probability that it was not excessive. The French nutritional recommendations for adults, or the European Union values when specific recommendations were lacking, were used as reference values. The previously published French implementation of the PANDiet (20,21) was modified for this analysis to include the WHO recommendation for free sugars (22). The content and construct validity of the PANDiet was verified and confirmed: the PANDiet was not correlated with energy intake and a higher PANDiet score was associated with not smoking, having a lower-energy-dense diet, and having higher plasma folate and carotenoid concentrations (data not shown). The PANDiet score is taken as the mean of the Adequacy and Moderation subscores and ranges from 0 to 100; the higher the score, the better the nutrient adequacy of the diet (Fig. 1).

Stepwise dietary counseling model

We developed a stepwise dietary counseling model based on the improvement in nutrient adequacy for each participant. The first step consisted of calculating the PANDiet score for the initial observed diet quality. We then randomly selected participants who had a PANDiet score below 60% and assigned them to the first step of the counseling model, which consisted of making food and beverage substitutions. We then calculated the PANDiet score for the modified diet and determined the magnitude of the improvement. This process was repeated for participants with lower PANDiet scores until all participants had a score above 60%.

The PANDiet score is calculated by the following formula:

\[
PANDiet = \frac{\text{Adequacy subscore} + \text{Moderation subscore}}{2}
\]

where the Adequacy subscore is composed of 21 items and ranges from 0 to 100, and the Moderation subscore is composed of 7 items, plus 12 potential penalty values, and ranges from 0 to 100.

The Adequacy subscore is composed of 21 items and ranges from 0 to 100; the higher the subscore, the better the intakes satisfy the nutrient requirements. The Moderation subscore is composed of 7 items, plus 12 potential penalty values, and ranges from 0 to 100; the higher the subscore, the more in line the intakes are with the reference values. EIEA, Energy Intake Excluding Alcohol; IoM, Institute of Medicine.
diet, 2) generating all of the possible food and beverage substitutions according to the initial observed diet, 3) calculating the change in the PANDiet score resulting from each substitution, and 4) selecting the substitution that resulted in the highest improvement in the PANDiet score. Iteratively, the next steps consisted of repeating the same actions from 1 to 4, starting from the diet that had been generated at the latest step. In this study, we arbitrarily limited the number of steps to 20.

### Food and beverage substitution scenarios

We used the stepwise dietary counseling model to simulate the improvement in the nutritional adequacy of the diet according to 3 different types of food and beverage substitutions with an a priori–graded implementation difficulty for the consumer. For these simulations, we used all of the food and beverages present in the food-composition database, except for vegetable oils, alcoholic beverages, tea, coffee, foodstuffs for particular nutritional uses (e.g., high-protein meal replacement), and foods that were not consumed by any of the participants during the study period. This resulted in a final number of 1105 food and beverages available for the model (i.e., 77% of the foods and beverages from the original food-composition database). Each type of food and beverage substitution was simulated through a dedicated “scenario.” The characteristics of each scenario are fully described in the subsequent paragraphs and are summarized in Table 1.

#### Scenario 1

The first scenario is based on the substitution of a food or beverage for its lower fat or lower sugar alternative. This scenario was assigned an a priori very low level of implementation difficulty for the consumer because of the construction of the food subgroups, which was based on the homogeneity of foods and beverages in terms of the amount consumed, similar usage, and cultural representation. The initial portion size of the product is retained, and the substitution occurs regardless of the moment or frequency of consumption. For example, a standard-fat cheese could be replaced with the same portion of a lower fat cheese. This scenario involves 130 foods and beverages classified into 20 food subgroups (Supplemental Table 1) and leads to a theoretical maximum of 99 substitutions per participant.

#### Scenario 2

The second scenario is based on the substitution of a food or beverage within the same food subgroup. This scenario was assigned an a priori low level of implementation difficulty for the consumer because of the construction of the food subgroups, which was based on the homogeneity of foods and beverages in terms of the amount consumed, similar usage, and cultural representation. The initial portion size is retained, and the substitution occurs regardless of the moment or frequency of consumption. For example, the white rice a participant ate could be replaced with the same portion of a lower fat cheese. This scenario involves 1105 foods and beverages classified into 64 food subgroups (Supplemental Table 2) and leads to a theoretical maximum of 28,044 substitutions per participant.

#### Scenario 3

The third and most complex scenario is based on the substitution of a food or beverage within the same food group. This scenario was assigned an a priori high level of implementation difficulty for the consumer because the food groups were based on the 64 subgroups present in the food groups, which are heterogeneous of foods and beverages in terms of amount consumed, similar usage, and cultural representation. The initial portion size of the replacement food was calculated by using a ratio based on the median portion of an item in the replacement subgroup and the median portion of an item in the initial food subgroup. The substitutions were constrained to within the same moment of consumption and 1 step of the stepwise dietary counseling model, which implies only 1 substitution per occurrence of consumption. For example, if a participant ate red meat several times during the 3 d of food recording, 1 portion of red meat could be replaced by an adjusted portion of salmon. This scenario involves 1105 foods and beverages classified into 11 food groups (Supplemental Table 3) and leads to a theoretical maximum of 109,601 substitutions per participant.

Simulations were conducted according to these 3 scenarios, resulting in 3 pathways comprising 20 steps for each of the 1330 participants.

### Statistical analysis

Weighting schemes proposed by the ENNS were used to account for the complex survey design and were adapted to the population sample analyzed. Continuous variables are presented as means ± SEMs, and categorical variables as percentages. An overall α level of 5% was used for statistical tests. When ANOVA identified a significant effect of the type of scenario, we used pairwise post hoc tests with Bonferroni correction to examine differences between the observed and each of the 3 final simulated diets. The empirical distributions for each item of the PANDiet (first quartile, median, and third quartile) in the observed and the 3 simulated diets were calculated. Because the changes in energy intake and PANDiet were not normally distributed, correlation coefficients between the initial energy intake and the change in energy intake and PANDiet were assessed by using Spearman’s correlations. SAS version 9.1.3 (SAS Institute) was used to conduct the simulations and to perform the statistical analyses.

### Results

#### Analysis of the nutrient changes between the observed and final simulated diets

At the end of the 20 steps of the stepwise dietary counseling model, 3 final simulated diets were obtained for each individual, corresponding to the 3 different scenarios. The mean PANDiet score, the mean Adequacy and Moderation sub-scores, and the mean energy and nutrient intakes in the observed and the 3 final simulated diets are described in Table 2. Compared with the mean PANDiet score of the observed diets (63.6 ± 0.2), the 3 scenarios significantly improved the nutritional adequacy of each of the simulated diets, with PANDiet scores resulting from each substitution, and

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Characteristics of the 3 food and beverage substitution scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>Scenario 2</td>
</tr>
<tr>
<td><strong>Type of food and beverage substitution</strong></td>
<td>Substitution of a food or beverage for a “lighter” alternative version</td>
</tr>
<tr>
<td><strong>Level of implementation difficulty</strong></td>
<td>A priori very low level because of the same organoleptic properties between a food and its “lighter” version</td>
</tr>
<tr>
<td><strong>Number of food and beverages involved</strong></td>
<td>130 items classified into 20 food subgroups</td>
</tr>
<tr>
<td><strong>Maximum number of substitutions per participant</strong></td>
<td>99 substitutions</td>
</tr>
<tr>
<td><strong>Portion size</strong></td>
<td>Initial portion size is retained</td>
</tr>
<tr>
<td><strong>Moment and frequency of consumption</strong></td>
<td>Not taken into account</td>
</tr>
</tbody>
</table>
scores of 66.9 ± 0.2, 90.0 ± 0.1, and 95.4 ± 0.1 for scenarios 1, 2, and 3, respectively. For scenario 1, the improvement in the PANDiet score was due solely to the improvement in the Moderation subscore, whereas in scenarios 2 and 3, the improvement in the PANDiet score was due to the improvement in both the Adequacy and Moderation subscores. The energy intake decreased in scenario 1 (Δ = −114 ± 2 kcal/d), did not change significantly in scenario 2 (Δ = −51 ± 6 kcal/d), and increased in scenario 3 (Δ = +204 ± 9 kcal/d). In scenario 1, the improvement in the PANDiet score was highly correlated with the decrease in energy intake introduced by the substitutions (ρ = −0.66, P < 0.0001), whereas in scenarios 2 and 3, the improvement in the PANDiet score was weakly correlated with both the initial energy intake and the change in energy intake (0.05 < p < −0.23, all P < 0.0001).

### Analysis of the nutrient adequacy of the observed and final simulated diets.

As expected from the nature of the different food and beverage substitution scenarios, scenario 1 improved the probability of adequacy for total fat, SFAs, cholesterol, total carbohydrate, and free sugars. For scenarios 2 and 3, the probability of adequacy was improved for almost all nutrients. The probability of adequacy for the lowest quartile of the population was >75% for all nutrients, except for vitamin D (0%), sodium (4%), and fiber (65%) in scenario 2 and for sodium (16%) in scenario 3 (Fig. 2).

### Analysis of the kinetics of improvement in global nutrient adequacy.

In scenario 1, no additional improvement in the PANDiet score was observed after 4 steps, whereas in scenarios 2 and 3, continuous improvements were observed through to the arbitrarily set limit of 20 steps. With both scenarios 2 and 3, only 4 steps were sufficient to achieve 50% of the increase in the PANDiet score observed at an upper limit of 20 steps (Fig. 3A). In scenario 1, no additional reduction in energy intake was observed after 4 steps, whereas in scenario 2, energy intake decreased on a continuous basis after the fourth step (although there was no eventual significant difference between initial and simulated energy intake); in scenario 3, the increase in energy intake tended to follow the evolution of the PANDiet score (Fig. 3B). In scenario 1, the kinetics of improvement in the PANDiet score was explained and paralleled by the kinetics of improvement in the Moderation subscore (because there was no improvement in the Adequacy subscore), whereas in scenarios 2 and 3, the kinetics of improvement in the PANDiet score was the result of combined improvements in both subscores (Fig. 3C, D).

### Analysis of the dietary changes between observed and final simulated diets.

Figure 4 shows how different food groups contributed to the improvement in the PANDiet score for the different substitution scenarios. In scenario 1, 52% of the increase in the PANDiet score was due to substitutions for lower fat alternatives in the butter and margarine subgroup and the hard- and soft-cheese subgroup and lower fat and lower sugar alternatives in the yogurt subgroup. In scenario 2, 51% of the

### Table 2: PANDiet score, Adequacy and Moderation subscores, and energy and nutrient intakes in the observed and simulated diets (ENNS 2006–2007)

<table>
<thead>
<tr>
<th></th>
<th>Observed diet</th>
<th>Final simulated diet 1</th>
<th>Final simulated diet 2</th>
<th>Final simulated diet 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>PANDiet score</td>
<td>63.6 ± 0.2</td>
<td>66.9 ± 0.2</td>
<td>90.0 ± 0.1</td>
<td>95.4 ± 0.1</td>
</tr>
<tr>
<td>Adequacy subscore</td>
<td>70.4 ± 0.3</td>
<td>70.4 ± 0.3</td>
<td>91.9 ± 0.2</td>
<td>98.0 ± 0.1</td>
</tr>
<tr>
<td>Moderation subscore</td>
<td>56.8 ± 0.4</td>
<td>63.4 ± 0.4</td>
<td>88.0 ± 0.2</td>
<td>92.8 ± 0.2</td>
</tr>
<tr>
<td>Energy intake, kcal/d</td>
<td>2128 ± 15</td>
<td>2014 ± 14</td>
<td>2077 ± 14</td>
<td>2323 ± 15</td>
</tr>
<tr>
<td>Protein, g · kg⁻¹ · d⁻¹</td>
<td>1.3 ± 0.01</td>
<td>1.3 ± 0.01</td>
<td>1.4 ± 0.01</td>
<td>1.5 ± 0.01</td>
</tr>
<tr>
<td>Total carbohydrate, % of EIEA/d</td>
<td>43.5 ± 0.2</td>
<td>44.5 ± 0.2</td>
<td>46.7 ± 0.1</td>
<td>48.2 ± 0.1</td>
</tr>
<tr>
<td>Fiber, g/d</td>
<td>18.9 ± 0.2</td>
<td>19.0 ± 0.2</td>
<td>34.9 ± 0.4</td>
<td>380.0 ± 0.2</td>
</tr>
<tr>
<td>Free sugars, % of EIEA/d</td>
<td>9.3 ± 0.2</td>
<td>7.6 ± 0.1b</td>
<td>6.4 ± 0.1c</td>
<td>6.2 ± 0.1c</td>
</tr>
<tr>
<td>Total fat, % of EIEA/d</td>
<td>38.4 ± 0.2</td>
<td>36.2 ± 0.26</td>
<td>33.3 ± 0.1c</td>
<td>32.7 ± 0.1c</td>
</tr>
<tr>
<td>SFAs, % of EIEA/d</td>
<td>16.2 ± 0.09</td>
<td>14.4 ± 0.09b</td>
<td>9.4 ± 0.05c</td>
<td>8.4 ± 0.03d</td>
</tr>
<tr>
<td>PUFA, % of EIEA/d</td>
<td>5.8 ± 0.06</td>
<td>5.8 ± 0.06c</td>
<td>8.3 ± 0.04c</td>
<td>8.9 ± 0.04c</td>
</tr>
<tr>
<td>Cholesterol, mg/d</td>
<td>385 ± 5</td>
<td>363 ± 5b</td>
<td>216 ± 3d</td>
<td>183 ± 3f</td>
</tr>
<tr>
<td>Vitamin A, mg/d</td>
<td>1.26 ± 0.07</td>
<td>1.19 ± 0.07</td>
<td>1.29 ± 0.04</td>
<td>1.33 ± 0.02</td>
</tr>
<tr>
<td>Thiamin, mg/d</td>
<td>1.3 ± 0.01c</td>
<td>1.3 ± 0.01c</td>
<td>3.1 ± 0.01c</td>
<td>1.8 ± 0.01c</td>
</tr>
<tr>
<td>Riboflavin, mg/d</td>
<td>2.0 ± 0.03c</td>
<td>2.0 ± 0.03c</td>
<td>7.1 ± 0.2c</td>
<td>2.2 ± 0.01c</td>
</tr>
<tr>
<td>Niacin, mg/d</td>
<td>19.8 ± 0.2</td>
<td>18.8 ± 0.2e</td>
<td>24.2 ± 2c</td>
<td>26.7 ± 0.2</td>
</tr>
<tr>
<td>Vitamin B-6, mg/d</td>
<td>1.8 ± 0.02c</td>
<td>1.8 ± 0.02c</td>
<td>2.3 ± 0.01c</td>
<td>3.5 ± 0.04c</td>
</tr>
<tr>
<td>Folate, μg/d</td>
<td>335 ± 3f</td>
<td>336 ± 3e</td>
<td>384 ± 2b</td>
<td>440 ± 2p</td>
</tr>
<tr>
<td>Vitamin B-12, μg/d</td>
<td>5.5 ± 0.1c</td>
<td>5.6 ± 0.1c</td>
<td>7.0 ± 0.1b</td>
<td>14.6 ± 0.2c</td>
</tr>
<tr>
<td>Vitamin C, mg/d</td>
<td>103 ± 2f</td>
<td>103 ± 2f</td>
<td>211 ± 3c</td>
<td>202 ± 3c</td>
</tr>
<tr>
<td>Vitamin D, μg/d</td>
<td>2 ± 0.1d</td>
<td>2 ± 0.1f</td>
<td>6.2 ± 0.2c</td>
<td>16 ± 0.2c</td>
</tr>
<tr>
<td>Vitamin E, mg/d</td>
<td>11.3 ± 1c</td>
<td>10.9 ± 1c</td>
<td>19.8 ± 0.2b</td>
<td>22.8 ± 0.2e</td>
</tr>
<tr>
<td>Calcium, g/d</td>
<td>992 ± 5b</td>
<td>1000 ± 9g</td>
<td>1335 ± 9e</td>
<td>1126 ± 7f</td>
</tr>
<tr>
<td>Magnesium, mg · kg⁻¹ · d⁻¹</td>
<td>4.56 ± 0.04c</td>
<td>4.55 ± 0.04c</td>
<td>7.14 ± 0.04b</td>
<td>8.05 ± 0.04c</td>
</tr>
<tr>
<td>Zinc, mg/d</td>
<td>12.2 ± 0.1</td>
<td>12.2 ± 0.1f</td>
<td>13.7 ± 0.1c</td>
<td>13.2 ± 0.1b</td>
</tr>
<tr>
<td>Phosphorus, g/d</td>
<td>1.35 ± 0.01c</td>
<td>1.36 ± 0.01c</td>
<td>1.63 ± 0.01b</td>
<td>1.80 ± 0.01b</td>
</tr>
<tr>
<td>Potassium, g/d</td>
<td>3.10 ± 0.02c</td>
<td>3.12 ± 0.02c</td>
<td>3.71 ± 0.02c</td>
<td>4.25 ± 0.02c</td>
</tr>
<tr>
<td>Iron, mg/d</td>
<td>13.2 ± 0.1c</td>
<td>13.0 ± 0.1f</td>
<td>19.0 ± 0.1b</td>
<td>20.2 ± 0.1c</td>
</tr>
<tr>
<td>Sodium, g/d</td>
<td>3.26 ± 0.03a</td>
<td>3.28 ± 0.03c</td>
<td>3.05 ± 0.05c</td>
<td>2.90 ± 0.05c</td>
</tr>
</tbody>
</table>

1 All values are means ± SEMs; n = 1330. ANOVA indicated a significant effect of the type of scenario for each variable. Labeled means without a common letter differ, as tested by pairwise post hoc comparisons with Bonferroni correction. EIEA, Energy Intake Excluding Alcohol; ENNS, Etude Nationale Nutrition Santé.
increase in the PANDiet score was due to substitutions for any food or beverage within the same food subgroup in 10 food subgroups. Although the fresh fruit, cakes and desserts, and bread subgroups all contributed strongly to the improvement in the PANDiet score, the improvement was mostly explained by substitutions within a very large number of subgroups and no subgroup contributed >8% to the increase in the PANDiet score. In scenario 3, 61% of the increase in the PANDiet score was due to substitutions for any food or beverage within the same food group in 3 groups: the meat, fish, and eggs group; the grains and starchy foods group; and the biscuits, pastries, desserts, and confectionary group.

Discussion

By using the stepwise dietary counseling model developed in this study, we simulated and evaluated the effects of 3 different types of food and beverage substitutions that aimed to improve the nutrient adequacy of the diet for each individual in a French adult population. We also compared the sequential efficiency of the 3 types of substitution, which were graded with regard to the degree of difficulty for the consumer to implement the dietary change. To our knowledge, this is the first study to report the simulated effects of successive food and beverage substitutions, with graded implementation difficulty for the consumer, on diet quality.

The most important finding from this study comes from scenario 2, which implies that a few simple changes in foods or beverages within food subgroups can result in marked improvements in diet quality, without changing the relative weight of these subgroups in the overall diet and keeping an a priori low level of implementation difficulty for the consumer. In this scenario, the PANDiet score for 90% of the population was $84$, whereas in the initial observed diet, this score was obtained by only $2\%$ of the population. Additionally, this scenario was very efficient in rapidly improving the diet quality: 50% of the PANDiet score increase was achieved after only 4 substitutions. On a theoretical note, this scenario shows great promise for the practical improvement in the diet quality of individuals, although the implementation of a counseling system is still far off.

Scenario 1 used food and beverage substitutions based on the existence of lower fat or lower sugar alternatives and only modestly improved the PANDiet score. As expected, this improvement was explained by the improvement in the Moderation subscore and was mainly due to substitutions for lower fat alternatives related to milks, dairy products, and fat spreads. Dietary counseling to use “lighter” products is a practical way to lower fat intakes (23,24), but, as we have shown here, the overall impact on diet quality is limited. In our study, the improvement in the PANDiet score was restricted to the few nutrients affected by such substitutions, but it may also have been limited by the number of available alternatives that are documented in the food-composition database we used. For example, Schickenberg et al. (25) identified 215 different products with suitable alternatives lower in saturated fat in their simulation study conducted in Dutch young adults, whereas we identified only 99 substitution possibilities.

Scenario 2 was designed to have a similar a priori level of implementation difficulty for the consumer than scenario 1, yet the scenario was powered by a much higher number of possible substitutions (28,044 vs. 99 substitutions in scenario 1). Indeed, the large number of possible substitutions may partly explain the marked PANDiet score increase. However, it is likely that the increase was largely due to the ability to modify a large spectrum of many different nutrients that could address the specific series of inadequate nutrient intakes in the initial diet, as indicated by improvement in both the Adequacy and Moderation subscores. The improvement in nutrient adequacy was due to substitutions among many food subgroups, demonstrating the multiplicity of dietary levers to improve nutrient adequacy. For example, Combris et al. (26) identified substitution for “better” cakes, pastries and bread as a promising lever to generate important improvements in terms of increasing the intake of fiber and decreasing the intake of sugar, fat, and sodium. In our study, improvement in each nutrient adequacy was dramatic for the population, with the exception of sodium (see below) and vitamin D. The nutrient adequacy of vitamin D was improved in a subset of the population who consumed fish and seafood during the recording period and were
therefore eligible to benefit from a substitution of another fish or seafood with higher vitamin D content (27).

Scenario 3 was designed to have an a priori higher level of implementation difficulty for the consumer because of the use of food and beverage substitutions that are based on a wider set of possibilities than in scenario 2 (109,601 vs. 28,044 substitutions in scenario 2). We expected that the improvement in the diet quality would be higher in this more liberal substitution scenario, yet this scenario proved to be only slightly more efficient in increasing the PANDiet score when compared with scenario 2. Furthermore, the improvement in nutrient adequacy was associated with a significant and undesirable increase in mean energy intake (Δ = +204 ± 9 kcal/d). The improvements in nutrient adequacy were largely due to the substitutions of meat and processed meat for fish (29% of the PANDiet score increase). Other studies have reported that decreasing meat and processed meat consumption was efficient in improving diet quality, but the importance of increasing fish consumption is more varied (14,28). Because the PANDiet is not correlated with energy intake (19), the increase in energy intake may be related in part to the ratio used to calculate portion size, which was based on the median portion size observed within each subgroup rather than a system based on energy equivalencies. Problems relating to portion size equivalence have been previously reported (13), and our findings support the notion that portion size equivalents vary considerably, in particular between different food groups; as a result, practical dietary relevance and consumer acceptability are issues when considering this scenario.

In both scenarios 2 and 3, the probability of adequacy of sodium intake did not increase significantly for more than one-quarter of the sample. Individuals in this subsample had a very low probability of adequacy of sodium intake in their initial observed diet, and the simulated food and beverage substitutions that reduced sodium intake resulted in a lower increase in the PANDiet score compared with those who improved their intakes of other nutrients (such as fiber and magnesium) but not of sodium. Failure to improve the adequacy of sodium intake may be a general limitation in diet modeling, as reported by others (29,30).

A major strength of this study is the use of a stepwise dietary counseling model, which provides practical successive dietary advice and shows the dynamic efficiency in improving the nutrient adequacy of observed diets in a representative sample of French adults. However, this study has limitations that need to be

FIGURE 3 Mean energy intake and variation in energy intake of the observed diet for the 3 simulated diets according to the number of steps in the stepwise dietary counseling model (A); mean PANDiet score and increment in the PANDiet score compared with the observed diet for the 3 simulated diets according to the number of steps in the stepwise dietary counseling model (B); mean Adequacy subscore and increment in the Adequacy subscore compared with the observed diet for the 3 simulated diets according to the number of steps in the stepwise dietary counseling model (C); and mean Moderation subscore and increment in the Moderation subscore compared with the observed diet for the 3 simulated diets according to the number of steps in the stepwise dietary counseling model (D) (Etude Nationale Nutrition Santé 2006–2007). The solid lines represent mean energy intakes, PANDiet scores, and Adequacy and Moderation subscores (right y axis) and the variation in energy intakes, PANDiet scores, and Adequacy and Moderation subscores compared with the observed diet (left y axis). The dashed lines represent the 95% CIs of the variation in energy intakes, PANDiet scores, and Adequacy and Moderation subscores compared with the observed diet. n = 1330.

FIGURE 4 Contribution of food groups and subgroups to the increment in the PANDiet score according to the food and beverage substitution scenario (Etude Nationale Nutrition Santé 2006–2007). For each scenario, the named food groups or subgroups together contributed to >50% of the variation in the PANDiet score. n = 1330.
considered when interpreting the results. One of the main limitations is that the results of this study depend on the number of foods and beverages contained in the food-composition database and the food classification system that we developed. A further limitation is that the nutrient and energy changes obtained by successive food and beverage substitutions are not entirely realistic, because for each substitution individuals may introduce other changes. For example, in scenarios 2 and 3, the large increase in fiber intake may promote satiety, which could lead to a reduction in total food intake (31,32). Finally, we did not attempt to take into account the economic or environmental impact of the food and beverage substitutions simulated here, despite understanding that they constrain the possibilities of dietary change (33,34).

The dietary advice simulated during scenario 2 provided a large, rapid improvement in the nutrient adequacy while keeping with an a priori low level of implementation difficulty. Such results offer promising perspectives in developing dietary intervention trials that would be based on modeling analyses (35).

In conclusion, this study shows that simple and acceptable substitutions within food subgroups can markedly and rapidly improve the nutritional adequacy of the diet of French adults. This method and strategy could be used to design efficient and tailored dietary counseling. For public health actions, the method and the present results could be used to identify the specific food groups that should be targeted and identify the relevant examples to be used in simple communications.

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Literature Cited


33. Wilson N, Nghiem N, Foster RH. The feasibility of achieving low-sodium intake in diets that are also nutritious, low-cost, and have familiar meal components. PLoS ONE. 2013;8:e58539.
