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Energy Allowances for Solid Fats and Added Sugars in Nutritionally Adequate U.S. Diets Estimated at 17–33% by a Linear Programming Model[1]

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Abstract

The 2010 Dietary Guidelines Advisory Committee has recommended that no more than 5–15% of total dietary energy should be derived from solid fats and added sugars (SoFAS). The guideline was based on USDA food pattern modeling analyses that met the Dietary Reference Intake recommendations and Dietary Guidelines and followed typical American eating habits. This study recreated food intake patterns for 6 of the same gender-age groups by using USDA data sources and a mathematical optimization technique known as linear programming. The analytic process identified food consumption patterns based on 128 food categories that met the nutritional goals for 9 vitamins, 9 minerals, 8 macronutrients, and dietary fiber and minimized deviation from typical American eating habits. Linear programming Model 1 created gender- and age-specific food patterns that corresponded to energy needs for each group. Model 2 created food patterns that were iso-caloric with diets observed for that group in the 2001–2002 NHANES. The optimized food patterns were evaluated with respect to MyPyramid servings goals, energy density [kcal/g (1 kcal = 4.18 kJ)], and energy cost (US $/2000 kcal). The optimized food patterns had more servings of vegetables and fruit, lower energy density, and higher cost compared with the observed diets. All nutrient goals were met. In contrast to the much lower USDA estimates, the 2 models placed SoFAS allowances at between 17 and 33% of total energy, depending on energy needs. J. Nutr. 141: 333–340, 2011.

Introduction

Solid fats and added sugars (SoFAS)[3] contribute ~35% of energy to the typical American diet (1,2). Providing most of the nonessential energy and few nutrients, SoFAS are said to be the root cause of dietary imbalance (1). The 2010 Dietary Guidelines Advisory Committee set SoFAS allowances at between 5 and 15% of energy intakes, depending on energy needs (1).

SoFAS allowances have replaced discretionary calories, featured in the 2005 Dietary Guidelines for Americans (1–5). Calculations of discretionary energy had been based on modeled food patterns (6) that met known nutrient needs, promoted moderation and balance, and took American food habits into account (7). Following a decision framework used to develop the Food Guide Pyramid (8), USDA researchers adjusted food group amounts when needed until a pattern either met the nutritional goals or came within a reasonable range (4). Decisions were based on the researchers' judgments of which food groups might reasonably provide the nutrients in question when the nutritional goals were not met (4). Further alterations were made to make food patterns conform better to educational goals (4,8).

An alternative approach to translating nutritional goals into food patterns is based on nonlinear or linear programming (LP) (9,10). A well-described diet optimization technique (11–14) has been used to create the Thrifty Food Plan (TFP) (2,15) and other USDA food plans at different levels of cost (16–18). LP models take into account, simultaneously, nutritional goals, American eating habits, and cost constraints (19–21). This study recalculated SoFAS allowances in modeled food patterns that met nutritional goals and took existing food selections into account. Following Britten et al. (4), separate food patterns were created for 6 gender-age groups. For each group, modeled patterns were created for 2 energy levels: recommended and observed.

Materials and Methods

In the present study, procedures used to develop MyPyramid food patterns (4) were followed (**Fig. 1**).

Establishing energy levels

The 6 gender-age groups were men and women aged 20–30 y; 31–50 y, and >50 y. Observed energy intakes for the 6 groups were based on 24-h

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[3] Abbreviations used: AI, adequate intake; FNDDS, Food and Nutrient Database; LP, linear programming; SoFAS, solid fats and added sugar; TFP, thrifty food plan.
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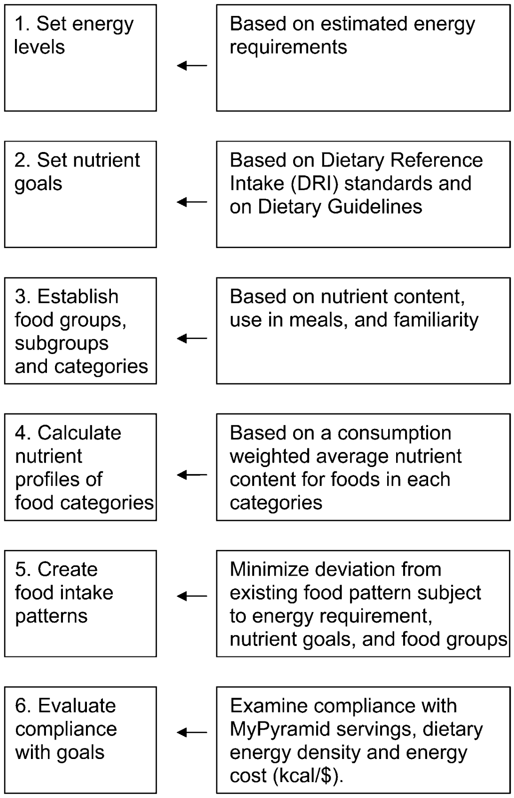

FIGURE 1 Process used to develop food intake patterns consistent with DRI recommendations and Dietary Guidelines [modeled after Britten et al. (4)].

recall from the 2001–2002 NHANES (22). The NHANES sample of 4295 individuals excluded pregnant women and persons consuming <600 kcal/d (23). Estimated energy requirements for each group were based on IOM (24) and USDA (3) standards (2000–2400 kcal for men and 1600–2000 kcal for women).

Establishing food groupings

Food groupings were based only on those foods that were consumed by NHANES participants. The number of foods consumed by NHANES 2001–2002 participants varied depending on gender-age groups (from 1129 to 2171 foods). Baby foods, alcohol, medical foods and supplements, electrolyte solutions, chewing gum, and foods with an energy density < 10 kcal/100 g (e.g. water, coffee, tea) were excluded. Nutrient composition of foods was obtained from the USDA Food and Nutrient Database 1.0 (FNDDS 1.0).

Individual foods consumed by each age-gender group of NHANES participants were aggregated into 128 food categories, 39 food subgroups, and 9 major food groups. The groupings largely followed the USDA coding system in FNDDS. The number of food categories varied from 85 to 128, whereas the number of food subgroups varied from 35 to 39. Consistent with the original Pyramid food groupings, the 9 major food groups were fruits; vegetables; meat, poultry, and fish; eggs; dry beans, legumes, nuts and seeds; milk, yogurt, and cheese; bread, cereal, rice, and pasta; fats and oils; and sweets. FNDDS food codes and subcodes may better correspond to what people eat in America than do more idealized food groupings developed by Marcoe et al. (25) and used in the Britten (4) process.

Establishing nutrient profiles and unit price (US$/100 g) of food categories

Nutrient profiles for each food category were calculated based on a weighted average of the nutrient contribution of each food, as based on the FNDDS 1.0 nutrient composition data (26) and frequency of occurrence in the 2001–2002 NHANES (2,4,15,27). The weights were assigned based on the relative amounts consumed. Values for solid fat and added sugar embedded in foods were obtained from the MyPyramid Equivalents Database (28) for USDA Survey Food Codes (version 1.0). The amount of added sugar in grams was calculated using a conversion factor of 4.2 (1 teaspoon = 4.2 g).

National food prices per 100 g of food, edible portion, were obtained from the 2001–2002 Center for Nutrition Policy and Promotion Prices database (29). The price per 100 g for each food category was calculated based on the weighted average of the unit price of each food. The weights were assigned based on the amounts consumed.

Establishing nutritional goals

Age- and gender-specific DRI values (30–33) were used for fiber, vitamins A, C, and E, thiamin, riboflavin, niacin, vitamin B-6, folate, and vitamin B-12 and for calcium, copper, iron, magnesium, phosphorus, selenium, zinc, potassium, and sodium. Because the potassium standard (4.7 g/d) is difficult to meet (4) it was relaxed to 90% of adequate intake (AI) (i.e. 4.23 g/d) following procedures adopted by the Thrifty Food Plan (15). Population-wide standards were used for protein, total carbohydrates, total lipids, SFA, linoleic acid, linolenic acid, cholesterol, and added sugar (24). These nutritional goals are summarized in **Table 1**.

Establishing consumption constraints

Gender- and age-specific consumption constraints were placed on food groups and subgroups and on each food category. Optimized amounts for the 9 food groups were flanked by the 10th and 90th percentiles of the observed consumption in the referent age-gender group (Table 1). Upper bounds for food subgroups and food categories were set by the 75th percentile of observed consumption of the referent age-gender group (Table 1).

Stringent criteria were imposed on introducing unfamiliar foods into the optimized food patterns. If a given food group or category was not consumed at all by a given age-gender group, it was not included in the optimized food intake patterns for that group.

The LP models

Model 1 produced optimized food patterns for the 6 gender-age groups by setting energy intakes at the recommended levels (4). Model 2

TABLE 1 Summary of constraints applied in all LP models

List	Unit/d	Value
Macronutrient constraints[1,2]		
Proteins	*% of TE*[3]	10–35
Total carbohydrates	*% of TE*	45–65
Total fats	*% of TE*	20–35
Linoleic acid	*% of TE*	5–10
Linolenic acid	*% of TE*	0.6–1.2
SFA	*% of TE*	≤10
Cholesterol	*mg*	≤300
Added sugar	*% of TE*	≤25
Micronutrient constraints[1]		
Fiber, vitamin A, thiamin, riboflavin, niacin, vitamin B-6, folate, vitamin B-12, vitamin C, vitamin E, calcium, copper, iron, magnesium, phosphorus, selenium, zinc, potassium, sodium	*g, mg, μg*	≥RDA[4] (or AI) ≤UL (when defined)
Consumption constraints		
Groups	*g*	>10th percentile
Groups	*g*	<90th percentile
Subgroups	*g*	<90th percentile
Categories	*g*	<75th percentile

[1] Macronutrient and micronutrient constraints come from DRI of the IOM. For potassium, 90% of the AI (i.e. 4.7 g/d) was used in constraint.
[2] Macronutrient recommendations were the same for all gender-age groups.
[3] Total energy.
[4] RDA were gender and age specific.

produced optimized food patterns by setting energy intakes at the levels observed for each group in the NHANES dataset. The LP models are summarized in **Figure 2**.

Decision variables and objective function. The LP model was based on 85–128 food categories (i.e. decision variables). The objective function measured the deviation between current consumption and the optimized food pattern for that age-gender group. The objective function was the sum of the absolute relative deviation (D_j) from each food subgroup j:

$$D_j = \left| \left(\sum_{i=1}^{i=I_j} Q_{ij} - Q_j^{obs} \right) \Big/ Q_j^{obs} \right|$$

To apply LP, the objective function was transformed into a linear function using a method based on goal programming, as described elsewhere (17,20). For this purpose, new decision variables ($\in \Re^+$) P_1 to P_j and N_1 to N_J, which represented the positive and the negative deviations from observed food subgroup quantity, were substituted to the absolute deviations D_j. The final linear function called F' was expressed as the sum of deviational variables (Fig. 2).

Deviational variable constraints. The new decisions variables called P_J and N_J were obtained adding a constraint (for each j), which defined the deviation between the observed amount of a food subgroup j and the amount of the same food subgroup in the optimized food pattern.

Energy constraints. In Model 1, the energy constraint was fixed equal to the energy requirement as established by the USDA for each age-gender group, following Britten et al. (4). In Model 2, the energy constraint was fixed equal to the average observed energy intake for that group in the NHANES dataset.

Nutrient recommendations. Nutritional goals or constraints, outlined in Table 1, ensured for each food pattern the achievement of the DRI for fibers, 9 vitamins, 9 minerals, proteins, total carbohydrates, total lipids, linoleic acid, linolenic acid, cholesterol, SFA, and added sugars.

Consumption constraints. Consumption constraints, gender and age specific, ensured that the optimized food patterns did not deviate too much from the usual eating habits of the American population. Each food category was limited to the 75th observed percentile whereas each food subgroup and food groups was limited to the observed 90th percentile of the observation distribution depending on gender-age groups. All optimized food patterns were computed with the Simplex method, which is implemented in the "proc optlp" procedure available in the Operational Research package of SAS version 9.2 (2009, SAS Institute).

Evaluating model performance

The first set of analyses, conducted with Models 1 and 2, measured compliance with MyPyramid goals. The observed diets and the food patterns were therefore converted into the MyPyramid food groups: fruits, vegetables, grains (whole and refined), meats and beans, milk and milk products, and oils. The second set of analyses, conducted with Model 2, addressed dietary energy density, and energy cost. For each age-gender group, dietary energy density (kcal/g), daily cost (US$/d) and

Model

Minimize $F' = \sum_{j=1}^{j=J} P_j + N_j$

Subject to :

(1) Deviational variables constraints $P_j - N_j = \left(\sum_{i=1}^{i=I_j} Q_{ij} - Q_j^{obs} \right) \Big/ Q_j^{obs}$ for each *j*

(2) Energy constraint $\sum_i Q_i \cdot E_i = E$

(3) Nutrient requirements $\sum_i Q_i \cdot B_{ik} \underset{\geq}{\leq} DRIs_k$ for each *k*

(4) Consumption constraints limited the amount of each

food group $P_g^{10} \leq \sum_i Q_{ig} \leq P_g^{90}$ for each *g*

food subgroup $\sum_i Q_{ij} \leq P_j^{90}$ for each *j*

and food category $Q_i \leq P_i^{75}$ for each *i*

Data

P_J = positive relative deviation between observed and optimized amount of food subgroup j

N_J = negative relative deviation between observed and optimized amount of food subgroup j

Q_i = amount of the food category *i* in the optimized food pattern

Q_{ij} = amount of the food category *i* from food subgroup *j* in the optimized food pattern

Q_{ig} = amount of the food category *i* from food group *g* in the optimized food pattern

E_i = amount of energy (kcal[1]) in 1g of the food category *i.*

B_{ik} = amount of the nutrient k in 1g of the food category *i.*

Q_j^{obs} = observed average amount of the food subgroup *j* in the referent age-gender group

E = energy requirement (model 1) or the observed energy intake (model 2) of the referent age-gender group

P_g^{10} = observed 10th percentile of the observed distribution of the food group *g*

P_g^{90} = observed 90th percentile of the observed distribution of the food group *g*

P_j^{90} = observed 90th percentile of the observed distribution of the food subgroup *j*

P_i^{75} = observed 75th percentile of the observed distribution of the food category *i*

[1] 1 kcal = 4.18 kJ

FIGURE 2 Description of the LP model.

energy cost (US$/2000 kcal) were computed for the observed diets and the optimized food patterns. Two kinds of energy density calculation were used. Energy density based on all foods (including liquid foods) was called total energy density (kcal/g), whereas energy density based on solid food only (34) was called solid energy density (kcal/g). In the 3rd set of analyses, SoFAS energy for each model and for each of the 6 food patterns were calculated as percentages of total daily energy (3,4).

All food patterns were expressed in percentage of DRI. Nutrients were identified as limiting when the amount of nutrient in the optimized pattern was exactly equal to the DRI.

Results

Each modeled food pattern satisfied the DRI for 9 vitamins and 9 minerals and was within the recommended ranges for protein, carbohydrate, fats, and essential fatty acids. Values for added sugars, SFA, cholesterol, and sodium were at or below the recommended levels (Table 1).

Model 1: recommended energy levels. In all 6 patterns, fruit and vegetable servings were close to or in excess of MyPyramid recommendations (**Table 2**). Model 1 favored vegetables and fruit more than any other food group. By contrast, numbers of servings for milk, yogurt, and cheese were below MyPyramid values. Servings of meat, poultry, and fish were below MyPyramid values for the 20- to 30-y age groups and above recommended values for older adults. Total grains servings (including whole grains) were low, in part because the grains group was high in sodium and low in potassium.

The present estimates placed SoFAS at between 273 and 606 kcal/d, which contrasted with the estimates of SoFAS in MyPyramid food patterns ranging from 132 to 362 kcal/d (Table 2) (3,4).

Model 2: observed energy levels. Food patterns that were isoenergetic with the observed diets were created by Model 2. The observed consumption of fruits, vegetables, whole grains, and milk, yogurt, and cheese fell short of MyPyramid recommendations, whereas refined grains and meat products were consumed in excess (**Table 3**). In the observed diets, energy derived from SoFAS ranged from 483 to 1045 kcal, depending on age and gender. Consistent with previous reports (1,2), SoFAS accounted for between 32 and 39% of total daily energy intakes.

Food patterns for men, optimized using Model 2, had more servings of fruits, vegetables, and whole grains, and fewer servings of refined grains and meats. The number of servings for milk and milk products increased for older men > 50 y. In nutritionally adequate diets, SoFAS allowances were between 378 and 869 kcal, representing a decrease of 200–300 kcal relative to observed values.

Food patterns for women had more servings of fruits, vegetables, and whole grains. For women in all age groups, the optimized food patterns contained more servings of meats and milk and milk products. SoFAS allowances were between 261 and 343 kcal, representing a decrease of 200–400 kcal relative to observed values.

Other characteristics of food patterns. The observed solid energy density decreased with age group (range, 2.2 to 1.9 kcal/g for men and 2.1 to 1.8 kcal/g for women), whereas the observed energy cost per 2000 kcal increased with age group (from US $3.8 to US$4.1 for men and from US$4.2 to US$4.8 for women).

Consistent with past studies (14,17,20), the optimized food patterns that were isocaloric with observed diets were lower in energy density and higher in daily diet costs and energy costs. Improvement in diet quality without a difference of energy

TABLE 2 Comparisons of MyPyramid recommendations with servings derived by Model 1[1,2]

	Men						Women					
	20–30 y (*n* = 400)		31–50 y (*n* = 756)		>50 y (*n* = 1012)		20–30 y (*n* = 377)		31–50 y (*n* = 742)		>50 y (*n* = 1008)	
	MyPyramid	Model 1	MyPyramid	Model 1	MyPyramid	Model 1	MyPyramid	Model 1	MyPyramid	Model 1	MyPyramid	Model 1
Energy,[3] *kcal/d*	2400	2400	2200	2200	2000	2000	2000	2000	1800	1800	1600	1600
MyPyramid food groups[4]												
Fruits, *cup/d*	2.0	3.9	2.0	3.4	2.0	3.2	2.0	3.7	1.5	2.8	1.5	2.7
Vegetables, *cup/d*	3.0	2.6	3.0	1.9	2.5	2.4	2.5	3.0	2.5	2.7	2.0	3.6
Total grains, *oz eq/d*	8.0	4.1	7.0	4.5	6.0	4.5	6.0	3.1	6.0	2.8	5.0	1.7
Whole grains, *oz eq/d*	4.0	1.0	3.5	1.4	3.0	1.5	3.0	0.9	3.0	1.1	3.0	0.4
Refined grains, *oz eq/d*	4.0	3.1	3.5	3.1	3.0	3.0	3.0	2.2	3.0	1.7	2.0	1.3
Meat and beans,[5] *oz eq/d*	6.5	5.7	6.0	7.8	5.5	6.5	5.5	5.2	5.0	6.4	5.0	5.7
Milk,[6] *cup/d*	3.0	1.7	3.0	1.8	3.0	2.5	3.0	2.0	3.0	1.8	3.0	1.8
Oils, *g/d*	31.0	33.5	29.0	21.3	27.0	25.7	24.0	32.8	24.0	22.9	22.0	23.6
Solid fat, *kcal/d*	NA[7]	273	NA	305	NA	278	NA	196	NA	157	NA	171
Added sugar, *kcal/d*	NA	333	NA	271	NA	103	NA	149	NA	162	NA	102
SoFAS, *kcal/d*	362	606	290	576	267	381	267	345	195	319	132	273

[1] MyPyramid recommendations data come from Britten et al. (4).
[2] Model 1 was based on the recommended energy intakes based on the energy requirement for each age-gender group and included DRI constraints and consumption constraints.
[3] 1 kcal = 4.18 kJ.
[4] Quantity equivalents for each food groups are: Fruits and vegetables, 1 cup equivalent is: 1 cup raw or cooked fruit or vegetable, 1 cup fruit or vegetable juice, 2 cups leafy salad greens. 1 cup = 237 mL. Grains, 1 ounce equivalent is: 1/2 cup cooked rice, pasta, or cooked cereal; 1 ounce dry pasta or rice; 1 slice bread; 1 small muffin (1 oz); 1 cup ready-to-eat cereal flakes. 1 ounce = 28 g. Meat and beans, 1 ounce equivalent is: 1 ounce lean meat, poultry, or fish; 1 egg; 1/4 cup cooked dry beans or tofu; 1 Tbsp peanut butter; 1/2 ounce nuts or seeds. 1 ounce = 28 g. Milk, 1 cup equivalent is: 1 cup milk or yogurt, 11/2 ounces natural cheese such as Cheddar cheese, or 2 ounces of processed cheese. 1 cup = 237 mL.
[5] This group also contained poultry, eggs, and fish.
[6] This group also contained milk products.
[7] NA, not applicable.

TABLE 3 MyPyramid food groups characteristics, cost (US$/d), energy cost (US$/2000 kcal), and energy density (kcal/g) of observed diets and optimized food patterns from Model 2, for men and women age groups[1]

	Men						Women					
	20–30 y (*n* = 400)		31–50 y (*n* = 756)		>50 y (*n* = 1012)		20–30 y (*n* = 377)		31–50 y (*n* = 742)		>50 y (*n* = 1008)	
	Observed	Model 2	Observed	Model 2	Observed	Model 2	Observed	Model 2	Observed	Model 2	Observed	Model 2
Energy,[2] *kcal/d*	2664	2664	2568	2568	1982	1982	1991	1991	1832	1832	1526	1526
MyPyramid food groups[3]												
Fruits, *cup/d*	1.2	4.0	1.1	3.7	1.3	3.2	0.9	3.7	0.9	2.8	1.2	2.6
Vegetables, *cup/d*	1.6	2.6	1.7	2.0	1.5	2.5	1.4	3.1	1.3	2.6	1.4	3.8
Total grains, *oz eq/d*	8.9	3.8	8.5	4.5	6.6	4.6	7.0	3.0	6.0	3.0	5.4	1.2
Whole grains, *oz eq/d*	0.5	0.9	0.6	1.4	0.9	1.5	0.5	0.9	0.6	1.2	0.8	0.3
Refined grains, *oz eq/d*	8.4	2.9	7.9	3.1	5.7	3.0	6.5	2.1	5.5	1.8	4.6	0.9
Meat and beans,[4] *oz eq/d*	7.8	5.9	8.2	7.9	6.2	6.5	5.1	5.3	5.2	6.6	4.3	5.5
Milk,[5] *cup/d*	1.9	1.7	1.7	1.7	1.4	2.5	1.5	2.0	1.3	1.7	1.2	1.8
Oils, *g/d*	19.0	36.5	21.0	30.4	16.0	25.1	16.0	32.6	17.0	24.1	14.0	20.6
Solid fat, *kcal/d*	530	294	526	343	402	276	396	195	367	163	281	160
Added sugar, *kcal/d*	515	575	436	503	277	102	375	148	314	154	202	101
SoFAS, *kcal/d*	1045	869	962	846	679	378	771	343	681	317	483	261
Diet characteristics												
Cost, *US$/d*	5.1	5.2	5.0	5.5	4.0	5.2	3.7	4.9	3.5	4.5	3.2	4.4
Energy cost, *US$/2000 kcal*	3.8	3.9	3.9	4.3	4.1	5.3	3.8	4.9	3.9	4.9	4.2	5.8
Total energy density,[6] *kcal/g*	1.3	1.1	1.4	1.1	1.4	1.1	1.3	1.1	1.4	1.1	1.3	0.9
Solid energy density,[7] *kcal/g*	2.2	1.9	2.1	1.9	1.9	1.4	2.1	1.6	2.1	1.5	1.8	1.1

[1] Model 2 was based on the average observed energy intake and included DRI constraints and consumption constraints.
[2] 1 kcal = 4.18 kJ.
[3] Quantity equivalents for each food groups are: Fruits and vegetables, 1 cup equivalent is: 1 cup raw or cooked fruit or vegetable, 1 cup fruit or vegetable juice, 2 cups leafy salad greens. 1 cup = 237 mL. Grains, 1 ounce equivalent is: 1/2 cup cooked rice, pasta, or cooked cereal; 1 ounce dry pasta or rice; 1 slice bread; 1 small muffin (1 oz); 1 cup ready-to-eat cereal flakes. 1 ounce = 28 g. Meat and beans, 1 ounce equivalent is: 1 ounce lean meat, poultry, or fish; 1 egg; 1/4 cup cooked dry beans or tofu; 1 Tbsp peanut butter; 1/2 ounce nuts or seeds. 1 ounce = 28 g. Milk, 1 cup equivalent is: 1 cup milk or yogurt, 11/2 ounces natural cheese such as Cheddar cheese, or 2 ounces of processed cheese. 1 cup = 237 mL.
[4] This group also contained poultry, eggs, and fish.
[5] This group also contained milk products.
[6] Calculated with all foods (including liquids).
[7] Calculated with solid food only (34).

intakes was associated with an increase of daily diet cost ranging from US$0.1 to US$1.2/d (Table 3).

MyPyramid SoFAS allowances, set by the USDA, ranged from 8.3 to 15.8% of total energy, depending on energy level (**Table 4**). The present allowances were between 17.1 and 32.8% of total energy intakes depending on energy intakes.

Identifying limiting nutrients. The USDA food patterns (4) met almost all nutrient goals, with the exception of potassium, sodium, and vitamin E. These can be regarded as limiting nutrients. Potassium, sodium, and vitamin E were also the limiting nutrients in the present models (**Table 5**). For calcium and sodium, the optimized diets were at exactly 100% DRI. Vitamin A was a limiting nutrient only for men. The present modeling analyses would suggest that calcium, potassium, vitamin E, and fiber may be nutrients of concern in the American diet.

Discussion

Based on the present LP model, optimized food patterns that meet all nutrient requirements contained up to 33% of energy from SoFAS, depending on energy level. The present estimates placed SoFAS allowances at between 17.1 and 32.8% of energy intakes, values in sharp contrast with the 2010 Dietary Guidelines Advisory Committee SoFAS allowances of 5–15% of energy (1).

The present LP models were in strict compliance with existing U.S. recommendations and guidelines. For example, the maximal amount of added sugars in the optimized food patterns was between 6.4 and 21.5% of total energy, below the 25% guidelines set by the IOM for the US (24). There are concerns that this value may be overly lax (35). It may be worthwhile to recalculate SoFAS using the stricter 10% guideline for added sugars, as set by the WHO (36) and the French authorities (37). However, even then, the likely SoFAS allowance is going to be higher than the 5–15% limit, due to the presence of solid fats in many nutrient-dense foods.

The LP methodology (9,10) offers an alternative approach to food pattern modeling (4). The present food patterns met all nutritional goals within prespecified energy needs, either recommended (Model 1) or observed (Model 2). The differences

TABLE 4 Percentage of SoFAS in food plans and in MyPyramid depending on energy levels

	Energy intake,[1] *kcal/d*						
	1600	1800	2000	2200	2400	2600	2800
				%			
Britten et al. (4)	8.3	11.0	13.4	13.0	15.0	15.8	15.2
Present study							
Women	17.1	17.7	17.3				
Men			19.1	26.2	25.3	32.8[2]	

[1] 1 kcal = 4.18 kJ.
[2] Mean of men's 2568 and 2664 kcal/d food plans.

TABLE 5 Optimized food patterns from the Model 1 expressed in percent of DRI[1]

Nutrients	Nutrient goals	Unit	Men			Women		
			20–30 y	31–50 y	>50 y	20y–30 y	31–50 y	>50 y
					% DRI			
Fiber[4]	21, 25, 30, 38	g/d	100	100	100	100	100	110
Vitamin A[2]	900, 700	μg/d	100	100	100	151	104	143
Vitamin C[2]	90, 75	mg/d	353	277	220	396	286	287
Vitamin E[5,6]	15	mg/d	100	121	100	100	100	100
Thiamin[2]	1.2, 1.1	mg/d	199	160	151	177	164	144
Riboflavin[2]	1.3, 1.1	mg/d	226	187	195	254	212	188
Niacin[2]	16, 14	mg/d	170	111	124	207	145	128
Vitamin B-6[4]	1.3, 1.5, 1.7	mg/d	293	200	173	255	219	175
Folate	400	μg/d	250	154	120	198	135	119
Vitamin B-12	2.4	μg/d	297	351	281	321	268	199
Calcium[3]	1000, 1200	mg/d	100	100	100	100	100	100
Copper	900	μg/d	236	337	190	162	229	184
Iron[4,7]	8, 18	mg/d	327	222	193	125	100	170
Magnesium[4]	310, 320, 400, 420	mg/d	115	117	102	123	139	121
Phosphorus	700	mg/d	220	267	239	191	229	195
Selenium	55	μg/d	155	214	217	152	179	145
Zinc[2]	8, 11	mg/d	114	151	132	174	197	153
Potassium[5]	4.23	g/d	110	100	100	100	100	100
Sodium	2300	mg/d	100	100	100	100	100	100
SFA	10	% TE[8]	100	97	100	95	85	89
Cholesterol	300	mg/d	70	100	100	80	100	76
Added sugar	25	% TE[8]	56	49	21	30	36	25

[1] Model 1 was based on the energy requirement.
[2] Nutrient goals were gender-specific.
[3] Nutrient goals were age-specific.
[4] Nutrient goals were gender and age-specific.
[5] In all of the 6 age-gender groups, RDA of vitamin E and potassium AI were not fulfilled in MyPyramid recommendations. In the present study, 90% of AI for potassium was used as a requirement.
[6] 1 mg of vitamin E = 1.5 IU of vitamin E.
[7] For men aged >51y and women between 20 and 50 y, the RDA of iron was not reached by MyPyramid recommendations.
[8] Total energy.

in Pyramid servings between current diets and optimized food patterns were considerable, as indicated in Table 3. The present model supports the notion that Americans need to make major changes in their food patterns to achieve nutritionally sound diets [i.e. increases of 1.5–3 cups (356–711 mL) of fruits, 1–2 cups (237–474 mL) of vegetables, and 0.5–1 oz eq (14–28 g) of whole grains, and decreases of 2–5 oz eq (56–140 g) of refined grains].

The present LP model differed in some important respects from past procedures (2,4,38). First, the principle that food patterns had to resemble American food selections, also espoused by the TFP and by Britten et al. (4), was strictly applied. Setting the objective function to minimize distance from the current consumption, similarly to TFP modeling, is the standard way to respect existing eating habits, an ostensible USDA goal. Consumption constraints prevented the model from selecting food categories that were never consumed by the referent population. Only those foods that were actually consumed by the different age-gender groups in the NHANES data were allowed to enter into the model and strict limits on consumption amounts were set to guard against unrealistic deviations from current eating habits. By contrast, the TFP had allowed for 10-fold increases in the consumption of selected foods, raising the question whether its low cost targets were achieved at the expense of ignoring both cultural and social norms (2). Britten et al. (4) allowed for a quadruple increase in the consumption of whole grains and a doubling in the consumption of dark green and orange vegetables and dry beans (4).

Second, the present LP model applied nutritional constraints for 9 vitamins, 9 minerals, dietary fiber, and 8 macronutrients (including added sugars), based on recommendations issued by authoritative bodies and expert panels (3,24,30–33,39). Compliance with MyPyramid servings was an output variable, as were energy density and energy cost. Britten et al. (4) first identified appropriate amounts from each food group and then cross checked them against amounts of energy, 9 vitamins, 8 minerals, 7 macronutrients, and dietary fiber (3,31). The amount of "discretionary energy" (equated to SoFAS) was calculated as the difference between total energy requirements and the energy that had to be consumed to meet nutrient needs. The present LP model treated SoFAS embedded in each food as an output variable while simultaneously taking into consideration all other nutrient needs.

Third, the present model used between 85 and 128 food groupings instead of 12 (4), making for more granular food choices. Nutrient composition of food groupings was weighed by amounts consumed, a procedure also used by others (15,25,27). The present food categories largely resembled the 96 mutually exclusive food categories, also based on aggregating unique foods in the 2001–2002 NHANES and previously published by the National Cancer Institute (40).

There were also similarities between prior studies and the present results. The present model identified a number of limiting nutrients, notably calcium and sodium at all energy levels, and potassium, fiber, and vitamin E at some energy levels as highlighted by Britten et al. (4) and Wilde et al. (2).

SoFAS are not discrete entities of known energy value. Rather, SoFAS are embedded in different foods from every food group (7). To minimize SoFAS, the consumer is steered toward fat-free milk, low-fat cheeses, extra lean meats or fish, whole grains, fresh fruit and vegetables (steamed, boiled, baked, or grilled). However, the similarity between the present results and previous LP models (2) suggests that the SoFAS allowances may be too stringent for selected nutrient guidelines to be achieved (38). For example, Gao (41) showed that, depending on energy level, compliance with MyPyramid recommendations (including those on discretionary energy) may be incompatible with achieving DRI for sodium or vitamin E (2,41).

Some study limitations need to be noted. Dietary intakes were based on 24-h recall, which precluded the individual long-term food selections from being taken into account. Hence, optimized food patterns were developed for population sub-groups rather than individuals, a procedure also followed by the USDA (4). Finally, the model was limited to food intakes from 2001–2002 NHANES and the linked food prices. An update may be required to better address current dietary recommendations and guidelines.

In conclusion, SoFAS allowances can and should be reduced from the existing level of 39% to 17–33%, depending on energy needs. Based on the current dietary recommendations and respecting American eating habits, the present LP model created food patterns than met all nutrient guidelines while permitting much more SoFAS than the MyPyramid diet allows. According to this LP model, that finding may mean the nutrition science community should consider making SoFAS recommendations more permissive, with the proviso that the present resetting of SoFAS allowances is not an invitation to eat more. Rather, SoFAS allowances are best spent by making a broader variety of nutrient dense food choices from every MyPyramid food group.

Acknowledgments

M.M. and A.D. conceived the study. M.M. conducted diet modeling. Both authors participated in the interpretation of the results and writing of the report. All authors read and approved the final paper.

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