

The shortest way to reach nutritional goals is to adopt Mediterranean food choices: evidence from computer-generated personalized diets^{1–3}

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ABSTRACT

Background: Dietary guidelines can be derived from dietary patterns known to be healthy such as the traditional Mediterranean diet. They can also be deduced by translating a set of nutrient recommendations into food combinations. However, the latter may vary depending on the decisions made by different expert committees.

Objective: The objective was to compare the effect of removing or adding selected nutrient recommendations on the dietary changes needed to fulfill a whole set of nutrient recommendations.

Design: For each adult participating in the French INCA dietary survey (Enquête Individuelle et Nationale sur les Consommations Alimentaires) ($n = 1171$), a nutritionally adequate diet was modeled that simultaneously met a whole set of nutrient goals (proteins, fiber, essential fatty acids, 10 vitamins, 9 minerals, sodium, saturated fatty acids, free sugars) while deviating the least from the observed diet in terms of food content. Eight sets of models were developed according to the inclusion or not of constraints on total fats, total carbohydrates, total MUFAs, and cholesterol.

Results: Compared with the observed intakes, fulfilling the whole set of nutrient constraints systematically decreased total fats and increased total carbohydrates, even in the absence of specific constraints on those macronutrients. For whichever model used, a strong consistency was observed in the dietary changes needed to fulfill the constraints, and the greatest increases were seen for unsalted nuts, unrefined grains, legumes, fruit, fish and shellfish, and vegetables.

Conclusion: Whether recommendations on total fats, MUFAs, or total carbohydrates are included or not in the definition of overall nutrient adequacy, foods typical of the Mediterranean diet are needed to reach overall nutrient adequacy. *Am J Clin Nutr* 2011;94:1127–37.

INTRODUCTION

Nutrient recommendations try to synthesize, through nutrients, all of the knowledge available on the relations between diet and health (1–3). However, people consume foods, not nutrients. It is thus necessary to advise the general public about healthy food patterns through dietary guidelines. Such advice can be based on an existing dietary pattern known to be associated with good health, such as the traditional Mediterranean diet (4–8). The advice can also be based on dietary guidelines specifically developed to help people from a given population meet their nutrient needs in a way that is culturally and socioeconomically acceptable (9–11).

Identifying which food should be consumed and in what quantity to fulfill the nutrient needs of a target population is a complex task that requires sophisticated approaches (11–13).

Individual diet modeling, in particular, is able to translate nutrient recommendations into combinations of real food choices while taking into consideration the individual variability of eating patterns in a given population (14–16).

One key problem in deriving dietary guidelines from nutrient recommendations is that the latter may vary depending on the positions adopted by different expert committees. This is particularly true for macronutrient intakes, for which clear evidence of a causal effect on health and disease is often lacking (17). Thus, low-fat (15–30% of energy) high-carbohydrate (55–75% of energy) diets with a low cholesterol content (<300 mg/d) have long been considered as the standard for a healthy diet and were widely recommended (18). However, the harmful consequences of very high refined carbohydrate and sugar intakes, in terms of obesity, diabetes, and cardiovascular disease (19, 20), have led international committees to increase the acceptable upper intake level of total fats (currently 35%) (21) and to decrease the minimum recommended intake of total carbohydrates (currently 50%) (22). Regarding specific lipids, such as MUFAs and cholesterol, the debate is both about their desired level and whether or not to set a specific recommendation for them (23–27). Surprisingly, the consequence of modifying a given nutrient recommendation on its feasibility and the dietary changes needed to meet the recommended intakes for a whole set of nutrients has seldom been addressed (28, 29).

The objective of the present study was therefore to analyze the effect of introducing recommendations on total fats, total carbohydrates, MUFAs, and cholesterol and combinations of these on the smallest required changes in food choices to reach overall nutrient adequacy for each individual in a representative sample of French adults.

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METHODS

Dietary data

The dietary data used in the present study were derived from the 7-d food records of adults ($n = 1171$; age >18 y) of the INCA cross-sectional dietary survey (Enquête Individuelle et Nationale sur les Consommations Alimentaires) conducted in 1999 (30). A food composition database was specifically developed for this survey (31). Alcoholic beverages, tea, and coffee were excluded from all analyses. All foods in the database were aggregated into 7 groups and 20 categories. For instance, the “unsalted nuts,” “vegetables,” and “fruit” categories (including fruit juices) were collapsed into the “fruit & vegetables” group. The “mixed dishes” category included food such as couscous-based dishes, paella, soups, and mixed meat and vegetable casseroles, and the “sandwich & pizza” category included food such as pizzas, quiches, and sandwiches; both were collapsed into the “mixed & sandwiches” group.

Individual diet optimization

The aim of individual diet modeling is to design, for each individual in a population, an optimized diet that is both individual-specific and nutritionally adequate (14). As previously described (14), for each INCA participant, the optimization process started from his or her observed diet (ie, 7-d food record and nutrient intakes) to design a new weekly modeled diet that simultaneously conformed with a whole set of nutrient constraints and that was the closest to his or her usual eating pattern to optimize acceptability.

As previously reported (14), the objective function was aimed at 1) preferentially choosing foods already declared as consumed by each individual in the 7-d food record, 2) minimizing the reduction of foods already consumed, and 3) introducing (in the lowest quantity possible) foods that were not declared as consumed (only if necessary for the fulfillment of the constraints) and preferentially selecting foods most frequently eaten by the French population to favor acceptability.

Constraints on food

Constraints on food quantities were introduced to ensure realism in the optimized diets. As previously described (14), an upper limit was set for the quantity of each particular food, each food category, and each food group. For a given food, the 95th percentile of consumers' intake distribution (ie, the distribution of quantities consumed by adults who consumed the food) was calculated and considered as an upper bound for each food in the database. For food groups and food categories, these limits were defined by the 95th percentile of the population intake distribution calculated for each sex. The total weight of optimized diets could not exceed 115% of the corresponding observed diet weight.

Constraints on nutrients

A common set of nutritional constraints was introduced in each case to ensure the nutritional adequacy of the optimized diets. As done and discussed before (14), each optimized diet was isocaloric to its corresponding observed diets and met a whole set of nutritional constraints (Table 1). The latter constraints were based on the WHO recommendations for proteins (18, 32), linoleic acid, α -linolenic acid, DHA and EPA, total omega-3 fatty

acids, total PUFAs (21), cholesterol, saturated fatty acids (SFAs), and free sugars (18); on the French recommendations (33) for fiber, 10 vitamins, and 9 minerals; and on the Nordic Nutrient Recommendations (34) for sodium.

For most nutritional constraints, the constraint levels were identical for all individuals, except for some vitamins and minerals. As previously described (14), safe upper limits for niacin, folate, ascorbic acid, vitamin A, vitamin B-6, vitamin E, zinc, and selenium were also applied in the optimized diets.

In the present study, 2 modifications were introduced in the set of nutritional constraints as compared with previous related studies (14, 29). First, the French Recommended Dietary Allowance for fiber used in this study was 30 g/d for men and women instead of 25 g/d. Second, the vitamin D constraint defining its minimum required level in the optimized diets was removed, given the difficulty to obtain sufficient amounts of vitamin D without relying on fortified dietary sources (14, 29). Consequently, in this study, we assumed that the inadequate vitamin D intake would be possibly corrected by either food fortification or supplementation, as generally agreed on (35).

Definition of several models derived from a BASAL model

Different optimized models were developed to test the effect of nutritional constraints, defined by fat and carbohydrate contributions to total energy intake, on the dietary changes needed to reach nutrient adequacy. Indeed, debated issues on those macronutrients have led international committees to recently revise their acceptable range for a healthy diet. We therefore used recent ranges—ie, 20–35% of energy and 50–75% of energy from total fats (21) and total carbohydrates (22), respectively. We also tested the effect of introducing constraints on cholesterol and MUFA. Even though most committees recommend diets with a low cholesterol content (3, 18, 36), others do not specify any recommended cholesterol intake for the general population (1, 26, 37). As for MUFA, most committees do not recommend a specific intake of MUFAs (24), whereas others do specify a desired range of MUFA intake (27, 36). For cholesterol, we used an upper bound of 300 mg/d, because, when specified, this maximal value was generally set for cholesterol intake (36, 38). For MUFA, we used the recommendation given by both the Spanish Heart Foundation and the French Food Security Agency—ie, 15–20% of total energy intake (27, 36).

Depending on the addition or subtraction of these constraints (or a combination of them), 8 different models were obtained (Table 1). The BASAL model was the first designed and included all of the constraints except for MUFA (which is not usually included in nutrient recommendations). Then, 4 other models were derived from the BASAL model by subtracting separately or simultaneously the constraints on total fats, total carbohydrates, and cholesterol (noted as “- Lip,” “- Carb,” “- Chol,” “-[Lip, Carb, Chol]”). Finally, 3 models (noted “+MUFA”) were also defined in reference to the traditional Mediterranean diet pattern (4, 39) and the new French recommendations for fatty acids in which a range of 15–20% of energy from MUFA is recommended (27). For each model, the modeling process generated 1171 optimized diets from the 1171 observed diets.

Choice of a model: the SELECTED model

The 8 models were compared on the basis of their effect on the macronutrients (ie, proteins, total fats, carbohydrates, MUFAs), on



TABLE 1
List of nutritional constraints included in each model¹

Nutrients	Constraints	BASAL	BASAL- Lip	BASAL- Carb	BASAL- Chol	BASAL- [Lip, Carb,Chol]	BASAL +[MUFA] (total)	BASAL +[MUFA]- [Lip,Carb] (SELECTED)	BASAL+ [MUFA] - [Lip,Carb,Chol]
Proteins (% of total energy)	10–20					Applied to all models			
Total fats (% of total energy)	20–35	Applied	Free	Applied	Applied	Free	Applied	Free	Free
Carbohydrates (% of total energy)	50–75	Applied	Applied	Free	Applied	Free	Applied	Free	Free
Cholesterol (mg/d)	≤300	Applied	Applied	Applied	Free	Free	Applied	Applied	Free
MUFA (% of total energy)	15–20	Free	Free	Free	Free	Free	Applied	Applied	Applied
α-Linolenic acid (% of total energy)	2.5–9					Applied to all models			
Linoleic acid (% of total energy)	≥0.5					Applied to all models			
DHA plus EPA (g/d)	≥0.25					Applied to all models			
Omega-3 (% of total energy)	0.5–2					Applied to all models			
PUFA (% of total energy)	6–11					Applied to all models			
Saturated fatty acids (% of total energy)	≤10					Applied to all models			
Free sugars (% of total energy)	≤10					Applied to all models			
Sodium (mg/d)	1500–2759 ²					Applied to all models			
Fiber, 10 vitamins, 9 minerals ³	≥EAR or OI or RDA ⁴					Applied to all models			

¹ In all models, optimized diets were isocaloric from observed diets, and the total weight was constrained between 85% and 115% of observed total weight. Carb, carbohydrate; Chol, cholesterol; EAR, Estimated Average Requirement; Lip, lipid; OI, observed intake; RDA, Recommended Dietary Allowance.

² A total of 2759 mg (ie, 7 g NaCl) was the maximal bound for men. For women, the maximal bound was 2365 mg (ie, 6 g NaCl).

³ In the current study, the French RDA for fiber was 30 g/d, whereas in the previous study (14) we used 25 g/d. The 10 vitamins were vitamin A, thiamine, riboflavin, niacin, pantothenic acid, vitamin B-6, folates, vitamin B-12, ascorbic acid, and vitamin E. The 9 minerals were calcium, phosphorus, potassium, iron, magnesium, zinc, copper, iodine, and selenium.

⁴ EAR values = 77% of RDA values. Constraints took into account the sex and age of each individual and the amount of the OI for each nutrient. The minimum levels imposed were as follows: at least the EAR when the OI was lower than the EAR, at least the RDA when the OI was greater than the RDA, and at least the OI when the amount was between the EAR and the RDA (14). Values of the French RDA used in this study for the 10 vitamins and the 9 minerals were previously published (14).

the cholesterol content of the optimized diets, and on the dietary changes needed to achieve the whole set of constraints.

The distribution (5th percentile, median, 95th percentile) of proteins, total fats, carbohydrates, MUFAs, and cholesterol were graphically represented among observed diets and optimized diets, separately for each model. Due to their skewed distributions, the nonparametric Wilcoxon's test for paired samples was used to compare macronutrients and cholesterol between the observed diets and optimized diets for each model. For each model, food categories were ranked depending on the median of their percentage weight variation, between the observed diets and optimized diets, among consumers (ie, individuals who consumed the food categories).

One model, called the SELECTED model, was chosen by comparing the results obtained with the 8 models tested in terms of macronutrient distribution and rank of food category variations. The rationale for choosing the SELECTED model is therefore presented in Results.

Sensitivity analysis of the nutritional constraints in the BASAL and SELECTED models

The optimization process produced a coefficient called “dual value” for each constraint. A nonnull dual value implied that the corresponding constraint was active. In other words, a nonnull dual value, induced by the optimization process, meant that fulfilling the constraint had a direct influence on food selection (ie, deviation

from observed individual food choices). In contrast, a null dual value indicated that the constraint was inactive. In the present study, the strength of each nutritional constraint in a given model was estimated by the percentage of optimized diets in which a nonnull dual value was recorded for that constraint. The strength of each nutritional constraint was statistically compared between BASAL and SELECTED models by using the McNemar test for paired data.

Identification of the dietary changes induced by the BASAL and SELECTED models

The variations recorded between observed and optimized diets for each food category were graphically represented for the BASAL and SELECTED models. For each food category, the percentage variation (and confidence limit) was calculated only for consumers (ie, individuals who consumed the food category). In addition, for each food category, the number of nonconsumers for whom the optimization process introduced a given food category into their modeled diet was calculated.

The mean quantity of each food group and food category was calculated for the observed diets and for the optimized diets obtained with the BASAL and SELECTED models. For each food group or food category, the difference between observed diets and diets optimized with the BASAL and SELECTED models was compared by using a pairwise Student's *t* test.

The Operational Research and the STAT packages of SAS version 9.2 (SAS Institute) were used to run linear programming

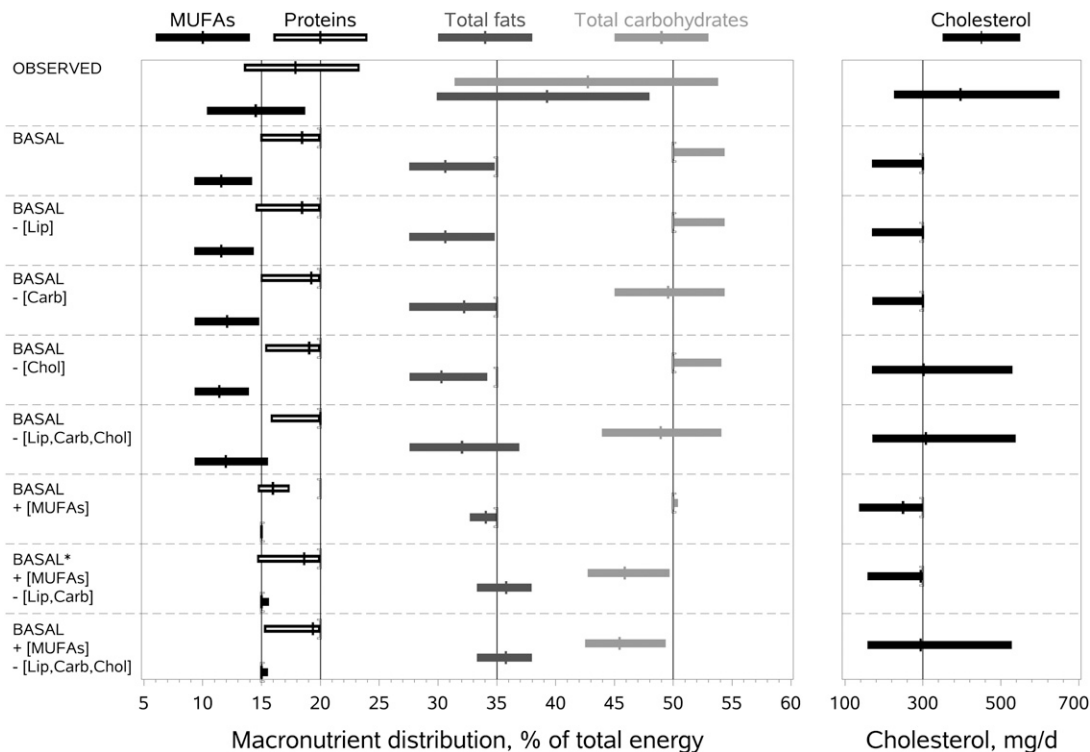


FIGURE 1. Distributions (5th percentile, median, 95th percentile) of MUFAs (% of total energy), proteins (% of total energy), total fats (% of total energy), total carbohydrates (% of total energy), and cholesterol (mg/d) in observed diets (upper row) and in diets optimized by using 8 different models. All of the models are defined in Table 1. The BASAL model included nutritional recommendations for proteins, total fats, total carbohydrates, essential fatty acids, fibers, vitamins, and minerals and limited recommendations for free sugar, sodium, saturated fatty acid, and cholesterol. The brackets indicate the level and the direction [minimal (or maximal)] of the bound imposed by the corresponding constraint. The brackets for the minimal total fats bound, maximal total carbohydrates bound, minimal proteins bound, and maximal MUFAs bound were not represented because those constraints were not active. *SELECTED model. Carb, carbohydrate; Chol, cholesterol; Lip, lipid.

models and to perform statistical analyses, respectively. An α level of 5% was used for all statistical tests.

RESULTS

Macronutrient and cholesterol distributions in the observed diets and in the diet optimized with the 8 models

A high variability of macronutrients and cholesterol intakes was noted in the observed diets of the subjects involved (**Figure 1**). Regarding the modeled optimized diets, they always contained a maximum of 20% energy from proteins because this constraint was imposed on all models. In addition, whatever the model used, the median values of total fats and cholesterol contents were lower in the optimized diets than in the observed diet, and the median carbohydrate content was higher.

More specifically, diets optimized with the BASAL model (including all constraints except on MUFA) contained no more than 35% energy from total fats, $\geq 50\%$ of energy from carbohydrates, and no more than 300 mg cholesterol/d, as imposed by the 3 corresponding constraints included in this model (**Figure 1**). Compared with the BASAL model, removing the total fats constraint (BASAL-[Lip]) had no effect on total fats distribution. Removing the carbohydrates constraint (BASAL-[Carb]) decreased the carbohydrate content (5th percentile = 45% compared with 50% of energy). Removing the cholesterol constraint (BASAL-[Chol]) increased the cholesterol content (95th percentile = 530 compared with 300 mg/d), and removing the 3 constraints simultaneously (BASAL-[Lip,Carb,Chol]) increased the 95th percentiles of total fats (from 35% to 37% of energy) and cholesterol (from 300 to 520 mg/d), and decreased the 5th percentile of carbohydrates (from 50% to 44% of energy). Diets optimized with the first 5 models contained less MUFA than did the observed diets (the median decreased from 14% in the observed diets to values lower than 12% in the first 5 models, and there was a shift of the whole distribution toward lower values).

In the last 3 models (BASAL+[MUFA]; BASAL+[MUFA]-[Lip,Carb]; BASAL+[MUFA]-[Lip,Carb,Chol]), a constraint was included to impose a minimum content of 15% of energy from MUFA to the optimized diets (**Figure 1**). In the (BASAL+[MUFA]) model, a very narrow distribution of values (ie, almost no variability) was observed for each macronutrient. In particular, all of the 1171 optimized diets contained exactly 15% MUFA and 50% total carbohydrates, showing that this model was unrealistic and by far the most constrained. Removing the total fats and carbohydrates constraints (BASAL+[MUFA]-[Lip,Carb]) allowed more variability in the macronutrient composition of the optimized diets, and then removing the cholesterol constraint (BASAL+[MUFA]-[Lip,Carb,Chol]) increased the cholesterol content (95th percentile = 520 compared with 300 mg/d).

Effect of each model on dietary changes needed to reach nutritional adequacy

The ranks of food category variations between observed and optimized diets were calculated (**Table 2**). To allow for comparison between models, food categories were sorted according to their rank in the BASAL model. An increase in unsalted nuts was recorded in all models, and this increase was the greatest recorded as compared with the other food categories. Fruit, fish, vegetables, unrefined starches and grains, legumes, fresh dairy products, and

vegetable oils were also invariably increased and were always in the top 10 categories (of 20). In contrast, refined grains and potatoes either increased or were unchanged, depending on the model, and were in an intermediate position (ranks 7–12). Except in the (BASAL+[MUFA]) model, soft drinks, poultry, salted snacks, eggs, sweets, and red meats either decreased or were unchanged and were in an intermediate-low position (ranks 10–16). Mixed dishes, cheese, deli meats, and animal fats were always decreased and in the last 4 positions and in the same order (17–20). The last 3 models with MUFAs were characterized by a high increase in vegetable oils (rank 2 or 3). The dietary variations induced by the last 2 models were almost the same, except for eggs, which recorded a less favorable ranking (13 instead of 11) in the model including the cholesterol constraint (BASAL+[MUFA]-[Lip,Carb]).

Choice of the SELECTED model

The (BASAL+[MUFA]-[Lip,Carb]) model was selected for further analysis and comparison with the BASAL model and then called the SELECTED model. The rationale for choosing this model among the 8 models was as follows: 1) a constraint on MUFAs was necessary because, without it, MUFAs were always reduced (**Figure 1**); 2) among the 3 models with MUFA, the (BASAL+[MUFA]) model was not retained because it was too unrealistic; 3) among the other 2 models with MUFAs, the model that included the cholesterol constraint (BASAL+[MUFA]-[Lip,Carb]) was preferred because the majority of official guidelines include a recommendation on cholesterol (3, 18). Without an upper limit on cholesterol, the median content will decrease in the optimized diets, but some of these diets will still contain very high amounts of cholesterol (95th percentile = 520 mg/d in the BASAL+[MUFA]-[Lip,Carb,Chol] model).

Sensitivity analysis of nutritional constraints in the BASAL and SELECTED models

The strength of each nutritional constraint was estimated by the percentage of optimized diets in which the constraint was active (ie, had a nonnull dual value). These percentages were compared both within and between the 2 models (**Table 3**). Keeping dietary energy equal to the observed levels was the most difficult constraint to fulfill: it was the only constraint that was active for 100% of individuals. Detailed analysis of the dual values obtained for that constraint indicated that the models would prefer to increase the energy content for 48% and 58% of individuals (and thus would prefer to decrease it for 52% and 42% of these individuals) in the BASAL and SELECTED models, respectively. The next constraints that were difficult to fulfill were those on the maximal content of SFA and sodium, the minimal contents of α -linolenic acid and calcium, and the maximal bound on total diet quantity (ie, $<115\%$ the observed weight). These constraints were active in $\geq 70\%$ of the optimized diets. All other constraints were active in less than two-thirds of the optimized diets, and their strengths were comparable between the 2 models. In particular, in the BASAL model, the constraint on total fats was quite inactive (active in only 4% of diets). In addition, constraints on carbohydrates and cholesterol were active in 56% and 51% of diets, respectively. In the SELECTED model, the constraint on MUFA was very strong (it was active in 92% of the diets optimized with this model) and had an effect on the ease to fulfill the constraints for other lipids. Thus, in the SELECTED model, as



TABLE 2

Rank of food categories according to the median of their percentage weight variation between observed and optimized diets for each model and only among consumers of each category¹

	N	BASAL ²	BASAL -[Lip]	BASAL -[Carb]	BASAL -[Chol]	BASAL-[Lip, Carb,Chol]	BASAL+[MUFA] -[Lip,Carb]	BASAL+[MUFA] -[Lip,Carb]
Food category								
Unsalted nuts	160	1(+)	1(+)	1(+)	1(+)	1(+)	1(+)	1(+)
Unrefined starches and grains	132	2(+)	2(+)	2(+)	3(+)	2(+)	6(+)	7(+)
Legumes	363	3(+)	3(+)	3(+)	2(+)	3(+)	8(+)	3(+)
Fruit	1071	4(+)	4(+)	5(+)	4(+)	5(+)	2(+)	6(+)
Fish and shellfish	974	5(+)	5(+)	4(+)	5(+)	4(+)	5(+)	4(+)
Vegetables	1155	6(+)	6(+)	6(+)	6(+)	6(+)	4(+)	5(+)
Fresh dairy products	1079	7(+)	7(+)	7(+)	9(+)	8(+)	7(+)	8(+)
Refined grains	1165	8(+)	8(+)	9(+)	8(+)	10(+)	11(+)	11(=)
Potatoes	838	9(+)	9(+)	10(+)	7(+)	7(+)	9(+)	9(=)
Vegetable oils	1170	10(+)	10(+)	8(+)	10(+)	9(+)	3(+)	2(+)
Soft drinks	456	11(=)	11(=)	12(=)	13(=)	12(=)	12(=)	13(=)
Poultry	922	12(=)	12(=)	11(=)	11(=)	11(=)	14(-)	10(=)
Sandwiches and pizza	894	13(=)	13(=)	14(=)	16(=)	15(=)	15(-)	16(-)
Eggs	786	14(-)	14(-)	15(-)	14(=)	13(=)	13(=)	11(=)
Sweet foods	1161	15(-)	15(-)	16(-)	12(=)	16(-)	10(+)	15(-)
Red meats	1147	16(-)	16(-)	13(=)	15(=)	14(=)	17(-)	14(=)
Mixed dishes	1162	17(-)	17(-)	17(-)	17(-)	17(-)	16(-)	17(-)
Cheese	1102	18(-)	18(-)	18(-)	18(-)	18(-)	19(-)	19(-)
Deli meats	973	19(-)	19(-)	19(-)	19(-)	19(-)	18(-)	18(-)
Animal fats	1169	20(-)	20(-)	20(-)	20(-)	20(-)	20(-)	20(-)

¹ Food categories are sorted according to their rank in the BASAL model. (+) indicates a significant increase between observed and modeled diets; (-) indicates a significant decrease between observed and modeled diets; (=) indicates that the median of the variation between observed and modeled diets was zero. BASAL-[Carb], BASAL model without constraints on total carbohydrates; BASAL-[Chol], BASAL model without the maximal constraint on total cholesterol; BASAL-[Lip], BASAL model without constraints on total lipids; BASAL-[Lip,Carb,Chol], BASAL model without constraints on total lipids, total carbohydrates, and total cholesterol; BASAL+[MUFA], BASAL model with constraints on MUFAs; BASAL+[MUFA]-[Lip,Carb], BASAL model with constraints on MUFAs and without constraints on total lipids and total carbohydrates; BASAL+[MUFA]-[Lip,Carb,Chol], BASAL model with constraints on MUFAs and without constraints on total lipids, total carbohydrates, and total cholesterol; N, the number of consumers of a given food category.

² Nutritional constraints included in BASAL model are listed in Table 1.

TABLE 3

For each nutritional constraint included in the BASAL and SELECTED models, the percentage of optimized diets in which the constraint was active sorted by decreasing order of the percentages recorded in the BASAL model¹

Nutrients	Constraints ²	BASAL (n = 1171)	SELECTED ³ (n = 1171)
Energy (kcal) ⁴	=	100	100
Saturated fatty acids (g)	<	94	100
Sodium (mg)	<	85	74
α -Linolenic acid (% of total energy)	>	77	70
Total amount (g) ⁵	<	77	73
Calcium (mg)	>	73	84
DHA plus EPA (g)	>	64	58
Iodine (mg)	>	61	62
Free sugar (g)	<	61	50
Magnesium (mg)	>	58	50
Total carbohydrates (% of total energy)	>	56	NA
Cholesterol (mg)	<	51	48
Fibers (g)	>	45	53
Ascorbic acid (mg)	>	39	39
Iron (mg)	>	29	29
Zinc (mg)	>	28	33
Total protein (% of total energy)	<	27	31
Riboflavin (mg)	>	27	21
Copper (mg)	>	23	20
Vitamin A (mg)	>	20	20
PUFA (% of total energy)	>	19	4
Panhotenic acid (mg)	>	17	17
Thiamine (mg)	>	16	13
Vitamin A (mg)	<	15	16
Selenium (mg)	>	13	13
Vitamin E (mg)	>	11	1
Potassium (mg)	>	8	7
Folates (mg)	>	7	6
Total fats (% of total energy)	<	4	NA
Vitamin B-6 (mg)	>	4	5
Linoleic acid (% of total energy)	<	3	23
Niacin (mg)	>	3	3
Sodium (mg)	>	1	2
PUFA (% of total energy)	<	0	1
Total amount (g) ⁵	>	0	1
MUFA (% of total energy)	>	NA	92

¹ Nutritional constraints represent the minimal bound for omega-3, linoleic acid, proteins, total fats, vitamin B-12, and phosphorus. Upper limits for MUFAs, omega-3, total carbohydrates, niacin, vitamin B-6, folates, ascorbic acid, vitamin E, selenium, and zinc are not presented because they were not active constraints. All nutritional constraints included in the BASAL model are listed in Table 1. The SELECTED model comprises the BASAL model with constraints on MUFAs and without constraints on total lipids and total carbohydrates. Constraints were considered as "active" when they had a nonnull dual value. NA, the constraint was not applied in this model.

² The minimum or maximum levels imposed on each nutritional constraint are listed either in Table 1 or in reference 14. = indicates that the energy constraint was equal to the observed energy intake; < indicates that the nutrient constraint imposed an upper bound; > indicates that the nutrient constraint required a minimal content.

³ For both the BASAL and the SELECTED models, nutritional constraints were sorted by decreasing order of the percentage of nonnull dual values recorded in the BASAL model. The McNemar test was used to compare the strength of each constraint between the BASAL and SELECTED models. All *P* values were significant except for iodine, ascorbic acid, iron, vitamin A, panhotenic acid, selenium, folates, niacin, and total amount.

⁴ Detailed analysis of the dual values obtained for the energy constraint showed that the models would prefer increasing the energy content in 48% and 58% of individuals in the BASAL and SELECTED models, respectively, and thus would prefer decreasing it in 52% and 42% of individuals in the BASAL and SELECTED models, respectively.

⁵ The total amount of each optimized diet was constrained between 85% and 115% of the weight of the corresponding observed diet.

compared with the BASAL model, it was slightly easier to find a sufficient amount of PUFAs and vitamin E and it was more difficult to maintain the amount of linoleic acid below the desired level. This is probably because MUFAs are positively associated with total PUFAs, including linoleic acid, and with vitamin E.

Dietary changes induced by the BASAL and SELECTED models

As shown in **Figure 2**, when a food category was increased by the BASAL (Figure 2A) or the SELECTED (Figure 2B) models, the mean variation between consumers in that specific category



was always <100% (ie, less than double the amount); the only exception was observed for unsalted nuts, which recorded very high variations, particularly in the SELECTED model (Figure 2B). The number of nonconsumers of each food category for whom the optimization process added that category in the corresponding optimized diet, for the BASAL (Figure 2C) and SELECTED models (Figure 2D), respectively, is also shown in Figure 2. Among the 13 food categories (out of 20) which had >5% of nonconsumers (ie, >60 nonconsumers), unsalted nuts, fruit, fresh dairy products, and fish were added for a large majority (ie, >75%) of nonconsumers. In fact, fish was added to all of them. Then, unrefined grains, legumes, poultry, and cheese were added to 17–30% of nonconsumers, depending on the model and on the category. Conversely, potatoes, soft drinks, salted snacks, eggs, and deli meats were never (or almost never) added, no matter which model was applied.

The average changes in daily food quantities induced by the optimization process with the BASAL and SELECTED models are shown in Table 4. For most food groups and food categories, the changes induced by the 2 models were in the same direction

and were of similar magnitude (although they could be significantly different). Thus, whatever the model used, the average optimized daily diets contained ~540 g fruit and vegetables, 260 g fresh dairy products, 60 g fish, and 70 g red meat. Mixed and sandwiches and sweets (including soft drinks) were reduced to ~140 g/d each, and animal fats were almost totally removed. Although unsalted nuts, unrefined starches, and legumes were among the food categories that increased the most (see Figure 2), their mean absolute content in the optimized diets was quite low (<25 g each) because of their low observed intakes. In contrast, for fruit, vegetables, and fish, both the variations and absolute quantities were large. The main differences between BASAL and SELECTED diets were observed for starches and grains (higher in the BASAL model) and for poultry, mixed dishes, and vegetable oils (higher in the SELECTED model).

DISCUSSION

In this study, we used individual diet modeling to investigate the smallest dietary changes needed to fulfill a whole set of nutrient recommendations by each individual in a representative

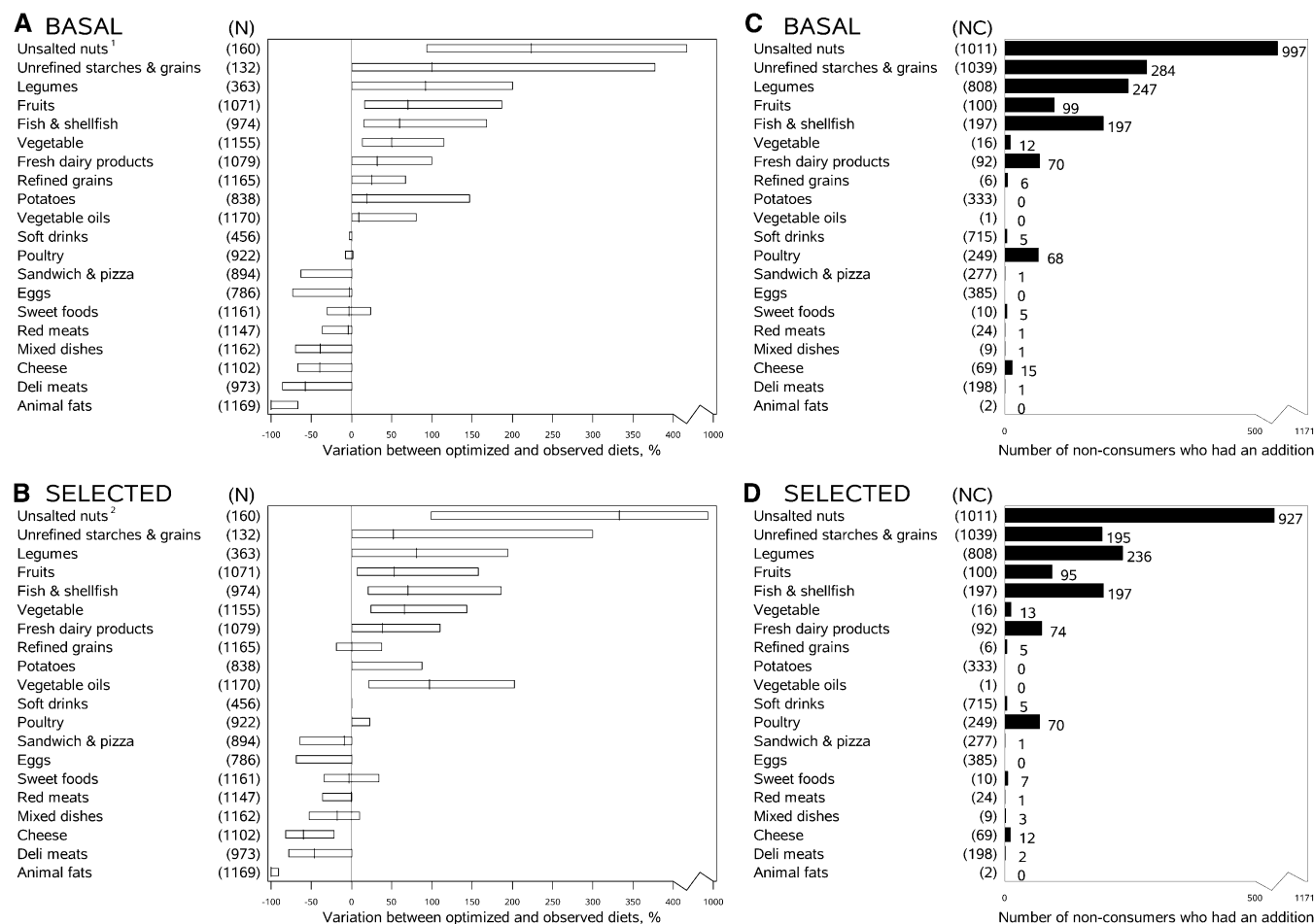


FIGURE 2. Food categories according to the median (and first and third quartile) percentage weight variation between observed and optimized diets among consumers for the BASAL (A) and SELECTED (B) models and the number of nonconsumers for whom the optimization added the category in his or her optimized diet for the BASAL (C) and SELECTED (D) model. For each food category, N was the number of consumers of that category, and NC was the number of nonconsumers (ie, N + NC = 1171). Food categories are sorted according to their rank in the BASAL model (see Table 2). All nutritional constraints included in the BASAL model are listed in Table 1. The SELECTED model represents the BASAL model with constraints on MUFAs and without constraints on total lipids and total carbohydrates. ¹The third quartile of the unsalted nuts percentage variation was equal to 597% (BASAL model). ²The third quartile of the unsalted nuts percentage variation was equal to 914% (SELECTED model).

TABLE 4Average amount (in g/d) of food groups and food categories in observed diets and in diets optimized with the BASAL and SELECTED models¹

	Observed (n = 1171)	BASAL (n = 1171)	SELECTED (n = 1171)
Fruit and vegetables	335 ± 196 ^a	543 ± 163 ^b	532 ± 165 ^c
Vegetables	137 ± 80 ^a	205 ± 71 ^b	221 ± 68 ^c
Fruit ²	197 ± 162 ^a	328 ± 154 ^b	302 ± 157 ^c
Unsalted nuts	1 ± 6 ^a	10 ± 10 ^b	10 ± 11 ^b
Meats, poultry, eggs, and fish	200 ± 81 ^a	177 ± 49 ^b	189 ± 57 ^c
Red meats	81 ± 49 ^a	67 ± 44 ^b	69 ± 46 ^c
Poultry	39 ± 38 ^a	34 ± 30 ^b	40 ± 35 ^a
Deli meats	28 ± 29 ^a	9 ± 10 ^b	11 ± 11 ^c
Eggs	18 ± 21 ^a	10 ± 11 ^b	10 ± 12 ^b
Fish and shellfish	35 ± 35 ^a	56 ± 28 ^a	60 ± 29 ^a
Starches and grains	229 ± 109 ^a	316 ± 87 ^b	268 ± 85 ^c
Refined grains	178 ± 98 ^a	215 ± 79 ^b	179 ± 77 ^a
Unrefined starches and grains	4 ± 15 ^a	19 ± 33 ^b	14 ± 28 ^c
Legumes	10 ± 22 ^a	24 ± 31 ^b	24 ± 29 ^b
Potatoes	37 ± 38 ^a	58 ± 52 ^b	51 ± 48 ^c
Dairy and cheese	233 ± 154 ^a	277 ± 125 ^b	275 ± 116 ^b
Fresh dairy products	191 ± 154 ^a	256 ± 131 ^b	260 ± 121 ^c
Cheese	42 ± 33 ^a	22 ± 15 ^b	15 ± 11 ^c
Mixed and sandwiches	226 ± 140 ^a	121 ± 79 ^b	159 ± 97 ^c
Mixed dishes ³	180 ± 135 ^a	91 ± 71 ^b	124 ± 89 ^c
Sandwiches and pizza	46 ± 50 ^a	30 ± 36 ^b	35 ± 46 ^c
Sweets	170 ± 145 ^a	144 ± 94 ^b	142 ± 90 ^b
Sweet foods	130 ± 85 ^a	117 ± 68 ^b	116 ± 64 ^b
Soft drinks	40 ± 109 ^a	26 ± 60 ^b	26 ± 60 ^b
Added fats	28 ± 15 ^a	19 ± 11 ^b	24 ± 10 ^c
Vegetable oils	12 ± 8 ^a	16 ± 9 ^b	23 ± 10 ^c
Animal fats	16 ± 12 ^a	2 ± 4 ^b	1 ± 2 ^c

¹ All values are means ± SDs. All nutritional constraints included in the BASAL model are listed in Table 1. The SELECTED model comprises BASAL model with constraints on MUFAs and without constraints on total lipids and total carbohydrates. ^{a,b}Indicates the significance of the differences computed by using Student's *t* test (Bonferroni corrected). Values sharing the same letter were not significantly different.

² Fruit juices were included in the fruit category.

³ Soups were included in the mixed-dishes category.

sample of French adults. Eight different models were designed to investigate the specific effects of recommendations on total carbohydrates, total fats, MUFAs, and cholesterol and combinations of them on the necessary minimal food changes needed to reach overall nutrient adequacy in adults. As compared with observed intakes, fulfilling the whole set of nutrient constraints systematically decreased total fats and increased total carbohydrates in the different models. This was obtained even in the absence of specific constraints on those macronutrients, thus underlining the importance of counteracting the nutrition transition-driven tendency of reducing carbohydrate intakes (40). In addition, in whichever model that was applied, the food categories most increased were those typical of the traditional Mediterranean diet, suggesting that, in this Western population, following Mediterranean steps was the shortest way to reach nutritional goals.

It has been proposed that dietary guidelines should be deduced from nutrient recommendations (9, 10). However, the intensity of the debate on some nutrient goals, especially those on total fats intake (17, 19, 41), suggests that such recommendations could have a huge effect on the definition of healthy eating. A surprising finding of this study was that the various sets of nutrient recommendations tested generated rather consistent food changes. Thus, both ranking and direction of food category variations were

consistent across models. The greatest increases were always seen for unsalted nuts, unrefined grains, fish/shellfish, fruit, vegetables, legumes, and fresh dairy products, and the greatest decreases were consistently observed for cheese, mixed dishes, deli meats, and animal fats. This supports the basic principles of dietary guidelines (42–44) and the validity of the traditional diet pattern promoted by the Mediterranean diet pyramid (4, 8). The only exceptions were the somewhat anomalous dietary changes induced by the model (BASAL+[MUFA]) in which all nutritional recommendations were imposed (it was the only model in which poultry was decreased and sweets increased), suggesting that the total fats limit (<35% of energy intake) and the total carbohydrates goal (>50% of energy intake) need to be relaxed to allow for an increase in MUFA intakes in the studied sample.

A strong consistency was also observed in terms of nutrient content. In whichever model that was applied, the optimized diets always contained less energy from total fats and more energy from carbohydrates than did the observed diets, even in the absence of constraints specifically related to those nutrients. This means that respecting the full set of constraints on fiber, micronutrients, and essential fatty acids and maximum limits on saturated fatty acids, sodium, and free sugars automatically induced an improvement (ie, decrease) of the lipid:carbohydrate ratio in the optimized diets. In addition, sensitivity analysis

showed that constraints on total fats and total carbohydrates were not the most severe ones, thus supporting the growing evidence that, to prevent chronic diseases, the quality of fats and carbohydrates is probably more important than their quantity (24, 45, 46). In contrast, imposing a maximum amount of cholesterol (<300 mg/d) was needed to prevent high cholesterol intake, which may present a risk for some individuals (47); and imposing a minimum energy percentage from MUFAs (ie, >15%) was necessary to avoid a systematic decrease in MUFA intake compared with the observed diets (as observed with all modeled diets without this constraint). This strongly suggests that a minimum intake of MUFAs should be explicitly listed in nutrient recommendations. In that respect, it is rather surprising that the WHO expert panel did not include a precise recommendation on MUFAs but recognized and stated their importance for maintaining insulin sensitivity and healthy concentrations of HDL and LDL cholesterol (21).

Sensitivity analysis showed that constraints on nutrients such as SFA, sodium, and free sugars as well as calcium, omega-3 fatty-acids, and iodine had the greatest effect on the food choices needed to reach overall nutrient adequacy. The constraint on MUFA was also very strong. In fact, increasing MUFAs by >15% seemed unrealistic, even in the absence of a constraint on total fats. When the MUFA constraint was applied, it was more difficult to maintain the amount of linoleic acid below the desired level, suggesting that MUFA and linoleic acid are associated in the French diet. Also, contrary to what is assumed by some committees (27, 36), it was not easier to limit SFA intake when a constraint on MUFA was included (SFA was the most difficult constraint to achieve in both the SELECTED and the BASAL models, ie, whether or not the constraint on MUFA was included). Although very strong, the constraint on MUFAs had an effect on only a limited number of food categories (especially vegetable oils). This explains that the diets optimized with the BASAL and the SELECTED models were in fact rather comparable. The common point was the key importance of foods typical of the Mediterranean diet pattern (especially unsalted nuts, unrefined grains, fish/shellfish, legumes, fruit, vegetables, and vegetable/olive oil) in the diets optimized with the 2 models. This observation gives additional support to the healthy Mediterranean diet pyramid, which was initially based on observational data (4), and to the recently updated "Mediterranean diet pyramid, a lifestyle for today" (8).

The main limitations of this study lie in our definition of an adequate diet, both in terms of nutrients and in terms of foods. First, by defining nutritional adequacy by the fulfillment of nutrient recommendations, we excluded nutritional characteristics of a healthy diet for which a quantitative recommendation should be set, such as having a low glycemic index or a high content of phytonutrients. Yet, given the large amount of fruit and vegetables and the increases in legumes and unrefined cereals in the optimized diets, our results suggest that specific constraints on the glycemic index and on phytonutrient content might not be necessary when all other nutritional constraints are fulfilled. Second, based on the observation that small dietary changes are more feasible to achieve than are large ones (48), our approach insists on minimizing the deviation from the observed diets (14). However, this decision might induce some bias. As an example, foods strongly recommended for healthy eating, such as unrefined cereals (49), unsalted nuts (50), and

legumes (49, 51), were greatly increased but had their mean absolute content remain quite low in the optimized diets (because of their initially very low observed intakes and the small percentage of consumers). Note that the amount of legumes in our optimized diets (24 g/d) was nevertheless greater than the legumes intake considered as beneficial in the original Mediterranean Diet Score (10 g/d) (39). In addition, due to our decision to depart the least from observed food intakes to favor acceptability, the amount of certain unfavorable food groups remained quite high in the optimized diets when compared with the traditional Mediterranean diet pattern (4). Thus, our results suggest that the Mediterranean diet pyramid should be interpreted as a goal showing the right direction rather than as a strict model to apply. Our results also support the conclusion of recently published studies showing that healthy diets can include more foods with an unfavorable nutrient profile than is generally recommended if foods with a favorable nutrient profile are also present in sufficient amounts (52–54).

In conclusion, in the present study, we went further than the observation that traditional Mediterranean foods (55), recipes (56), and diet pattern (57) were associated with a high nutrient adequacy. Indeed, we showed that improvements in food habits by following food choices typical of the Mediterranean diet pattern were strictly needed to fulfill nutrient recommendations in the French population. Finally, we suggest that applying the present diet-modeling approach to populations of non-Mediterranean origins could be useful in identifying food choices that are both nutritionally and culturally appropriate for them, considering that Mediterranean food choices could be irrelevant to such populations (58).

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The authors' responsibilities were as follows—MM, CI, DL, and ND: conceived the study; MM: conducted data modeling and statistical analyses; and FV: participated in the conception of the study and in data modeling. All of the authors participated in the interpretation of the results and in writing of the research paper. None of the authors had a potential conflict of interest.

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