Public Health Nutrition: 24(16), 5539–5549 doi:10.1017/S1368980021002871

Public health potential of guidelines-based dietary scores for non-communicable diseases mortality prevention: simulation study using the Preventable Risk Integrated ModEl (PRIME) model

Chantal Julia[1,2,*], Pascal Leroy[3], Moufidath Adjibade[1], Karen E Assmann[1], Mathilde Touvier[1], Serge Hercberg[1,2], Louis-Georges Soler[3] and Emmanuelle Kesse-Guyot[1]

[1]Sorbonne Paris Nord (Paris 13) University, Inserm U1153, Inrae U1125, Cnam, Nutritional Epidemiology Research Team (EREN), Epidemiology and Statistics Research Center, University of Paris (CRESS), SMBH Paris 13, 74 Rue Marcel Cachin, F-93017 Bobigny, France: [2]Public Health Department, Avicenne Hospital (AP-HP), Bobigny, France: [3]Université Paris-Saclay, INRAE, UR ALISS, Ivry-sur-Seine, France

Submitted 10 December 2020: Final revision received 26 March 2021: Accepted 28 June 2021: First published online 2 July 2021

Abstract

Objective: Dietary indexes measure the adherence of individuals to a set of nutritional recommendations. However, the health gains associated with adherence to various dietary indexes may vary. Our objective was to compare the magnitude of estimated avoided deaths by chronic diseases obtained by improving diet quality in the French population, measured by a variety of dietary indexes.
Design: Simulation study based on observational data.
Setting: Weighted data from a French population-based cohort study.
Participants: In participants from the NutriNet-Santé cohort, we computed dietary scores reflecting the adherence to various recommendations (Medi-Lite, Healthy Diet Indicator (HDI), Programme National Nutrition Santé/National Nutrition and Health Program – Guidelines Score, Diet Quality Index (DQI), Alternative Healthy Eating Index (AHEI) and the modified Food Standards Agency nutrient profiling system dietary index (FSAm-NPS DI)). Quintiles of the food groups' consumption and dietary intakes were used as input in a simulation model (Preventable Risk Integrated ModEl (PRIME)), yielding the number of delayed or avoided deaths in nutrition-related non-communicable diseases, comparing between very high or very low nutritional quality of the diet and medium nutritional quality.
Results: A modification of dietary intakes from medium quality to very low quality (i.e. from the middle quintile to the quintile with the lowest nutritional quality) was associated with an increased number of deaths ranging from 3485 (95 % uncertainty interval (CI) 4002, 2987) for HDI and 3379 (95 % CI 3881, 2894) for FSAm-NPS DI to 838 (95 % CI 1163, 523) for Medi-Lite. Conversely, a modification of dietary intakes from medium quality to very high quality was associated with a decrease in the number of deaths ranging from 1995 (95 % CI 1676, 2299) for Probability of Adequate Nutrient intake diet, 1986 (95 % CI 1565, 2361) for DQI-International, 1931 (95 % CI 1499, 2316) for FSAm-NPS DI and 858 (95 % CI 499, 1205) for HDI.
Conclusions: Our results provide some insights as the potential impact of following various dietary guidelines to reduce mortality from nutrition-related diseases.

Keywords
Non-communicable diseases
Dietary recommendations
Public health impact
Mortality
Simulation study
Dietary index
Nutrient profile

In 2016, non-communicable diseases (NCD) including CVD and cancers were the two leading causes of death in high-income countries, representing 66 % of overall mortality[1].

According to the Global Burden of Diseases project, behavioural risk factors currently outweigh environmental and metabolic risks worldwide[2]. Among those, dietary risks appear as one of the leading risk factors for NCD, along with exposure to tobacco and alcohol[2]. Worldwide, dietary risk factors were responsible of an average 11 million deaths from NCD in 2017, with high intake of Na and low intake of whole grains and fruit as

*Corresponding author: Email c.julia@eren.smbh.univ-paris13.fr

the leading dietary risk factors[3]. Those dietary factors are mostly modifiable arguing for the implementation of nutritional public health programmes targeting both the individual through education and the collective environment through marketing restrictions, front-of-pack labelling or taxation of less healthy foods[4]. National nutrition programmes largely rely on the dissemination of food-based guidelines based on food and nutrient requirements for the population. Current public health initiatives in France also include the implementation of a front-of-pack nutrition label – the Nutri-Score – to help consumers making healthier choices in purchasing situations[5–7].

To investigate the associations between adherence to dietary guidelines or dietary requirements and health, a very common method is the construction of a numerical dietary index that assesses the quality of the diet through the compliance to the guidelines. Recent reviews document the existence of up to twenty-five different individual dietary indexes assessing overall dietary quality mostly through the adherence to dietary guidelines[8,9].

A few recent dietary indexes have been developed taking into account the nutrient profile of the foods consumed by the individual[10–12]. These dietary indexes appear as innovative, as they build upon an evaluation of the nutritional quality at the food level, investigating the effect of food choices on the overall diet. Also, nutrient profiling systems are useful tools for public health nutrition interventions, as they can serve as a basis for labelling, marketing restrictions or fiscal policies[13], which may impact dietary behaviour. The FSAm/HCSP score (Food Standard Agency Nutrient Profiling System, modified by the High Council for Public Health – Haut Conseil de la Santé Publique), adapted to the French context, is the nutrient profiling system underlying the French official front-of-pack labelling system, the Nutri-Score[14]. A dietary index based on the FSAm/HCSP of the foods consumed (the FSAm-NPS DI for modified Food Standard Agency Nutrient Profiling System-Dietary Index), reflecting the overall quality of the diet at the individual level, has recently been validated in France[10,15].

Overall, dietary indexes are built as a measure of distance between individual behaviour and a set of nutritional recommendations (from national or international organisations, or corresponding to specific dietary patterns, as the Mediterranean diet). Dietary indexes also allow to measure the distance between individuals in terms of dietary behaviour, in order to establish association with health outcomes. However, given that these recommendations may put emphasis on varying elements in the diet, the criteria that are used in the construction of dietary indexes vary as well and they may capture the nutritional quality of diets in differing ways. In a public health perspective, it appears therefore of importance to determine which dietary indexes best discriminate the variability between individual behaviour and allow identifying at risk groups for which dietary modifications would lead to substantial health gains. This is of utmost importance to guide the implementation of efficient policies that allow preventing nutrition-related diseases in the long term, in particular in vulnerable groups.

Most studies investigating the link between dietary indexes and health are based on cohort studies and evaluate in a prospective design the association between a dietary index and subsequent health events[16–18]. Epidemiological findings on diseases risks have led to the development of methods and tools to estimate the number of deaths and chronic disease cases attributable to specific behavioural risk factors using modelling techniques. Some models allow to estimate the number of deaths avoided associated with dietary changes by simulating counterfactual scenarios[19]. These tools are of high interest for investigating the impact of public health interventions on population health. Moreover, they can provide direct assessments of their comparative effectiveness, allowing to select the most efficient intervention strategies. In the case of public health interventions aimed at modifying dietary behaviour – such as the dissemination of dietary guidelines or nutrition labelling – it is crucial to investigate the potential public health gain associated with various sets of recommendations, assessed using dietary indexes.

To the best of our knowledge, no study has yet compared the number of deaths avoided by improving nutritional quality of the diet using different dietary indexes, and in particular using indexes related to food choices, dietary requirements or food-based guidelines in the same study allowing direct comparisons.

The aim of the present work is to compare the magnitude of estimated avoided deaths by chronic diseases obtained by improving diet quality in the French population, measured by a variety of dietary indexes.

Materials and methods

Population

The NutriNet-Santé cohort was launched in France in May 2009, with enrolment and participation taking place online via a dedicated and secure Web interface (www.etude-nutrinet-sante.fr). Volunteers with Internet access aged ≥ 18 years are recruited by recurrent multimedia campaigns[20]. The provision of informed consent and an electronic signature is mandatory for enrolment. Upon enrolment, participants are asked to complete a set of five questionnaires: sociodemographics and lifestyles, health status, physical activity, anthropometrics and diet (repeated 24-h records).

Data collection

Dietary data

At baseline and each year thereafter, participants were invited to complete three non-consecutive 24-h dietary

https://doi.org/10.1017/S1368980021002871 Published online by Cambridge University Press

records, randomly assigned over a 2-week period (2 weekdays and 1 weekend day). Participants reported all foods and beverages consumed at each eating occasion via a web-based 24-h dietary record tool designed for self-administration. These online records have been validated against interview by a trained dietitian and against urinary and blood biomarkers, showing that web-based tools exhibit an adequate validity of estimated dietary intakes – including salt intake[21,22]. The consumed portions were indicated using validated photographs of portion sizes[23], household measures or by indicating the exact quantity (g) or volume (ml). For the present study, we used the dietary data from the first 2 years of follow-up, considered as baseline dietary intake. Daily food intake refers to the average consumption from all available 24-h dietary records, weighted according to the type of day (weekdays or weekend). Energy and nutrient intakes were estimated using the NutriNet-Santé composition table including more than 3000 food items[24]. Dietary under-reporting was identified using the method proposed by Black[25], comparing energy intake to the BMR (estimated using Schofield equations), taking into account the physical activity level. Under-reporting subjects were then excluded from the analyses using the Goldberg cut-off for energy intake.

Dietary indexes computation

A variety of dietary indexes reflecting adherence to a specific diet or to nutritional guidelines were computed, using French and international recommendations supported by recognised institutions. Dietary indexes were selected based on their use to define dietary recommendations or nutritional policies. We computed two dietary indexes based on French food-based and nutritional recommendations, namely the PNNS-GS (for Programme National Nutrition Santé/National Nutrition and Health Program – Guidelines Score)[26] and the PANDiet (Probability of Adequate Nutrient intake diet)[27] and one dietary index based on American guidelines (Alternative Healthy Eating Index)[28]. To focus specifically on diet, we removed the physical activity component from the PNNS-GS as previously described[29]. For adherence to the Mediterranean diet, the Medi-Lite, a recent Mediterranean diet adherence index[30], was computed. Two international dietary indexes, namely the DQI-I (Diet Quality Index-International)[31] and the HDI (Healthy Diet Indicator) developed by the WHO[32], have also been calculated.

Finally, we computed the FSAm-NPS DI, based on the nutrient profiling system (FSAm/HCSP) of the foods consumed[10].

For dietary indexes other than the FSAm-NPS DI, lower quintiles correspond to a lower nutritional quality of the diet, while higher quintiles reflect a higher nutritional quality of the diet. For the FSAm-NPS DI, lower quintiles reflect a higher nutritional quality of the foods consumed, while higher quintiles reflect a lower nutritional quality of the foods consumed. Therefore, for clarity purposes, ranking in the FSAm-NPS DI was reversed so that lower scores reflected lower nutritional quality of the diet and higher scores higher nutritional quality of the diet, as for other dietary indexes.

The summary of components and scoring of each dietary index are described in Supplemental Table 1.

Sociodemographic and lifestyle data

At enrolment, volunteers provided information on sex, date of birth, educational level (less than undergraduate, undergraduate or postgraduate), socio-professional status (never-employed/other activity, self-employed, employee, intermediate profession and managerial staff or superior intellectual profession) and cohabiting status (living alone, cohabiting or separated/divorced/widowed), using self-administered web questionnaires[33]. Monthly household income was provided and estimated per consumption unit according to household composition using the French formula from the national statistical office INSEE[34]. Categories of monthly household income per consumption unit were defined as follows: <1200, 1200–1800, 1800–2700, >2700 euros and a category of participants who refused to disclose their income.

Smoking status (never, former or current smoker) was assessed using self-reported data, and physical activity data (<30 min of physical activity/d; equivalent to brisk walking/d), moderate physical activity (≥30 and <60 min) or high physical activity (≥60 min) were collected using a short form of the French version of the International Physical Activity Questionnaire[35]. The International Physical Activity Questionnaire is a validated tool, based on three specific types of physical activity: walking, activities of moderate intensity and activities of vigorous intensity. Energy expenditure expressed in metabolic equivalent task min/week was estimated and classified according to the French guidelines for physical activity. Baseline height and weight were assessed using a self-administered anthropometric questionnaire[36], and BMI was calculated as the ratio of weight to squared height (kg/m^2).

Statistical analysis

Food and nutrients intake were estimated across weighted quintiles of each dietary index. Weights were calculated separately for each gender using the iterative proportional fitting procedure according to 2009 national census reports on age, occupational category, education, area of residence and marital status (<18 years)[37]. The weighting procedure allowed for the collected dietary data to be more representative of the overall adult French population.

Partial Spearman correlation coefficient adjusted for energy intake between dietary indexes and weighted κ across quintiles was computed.

Baseline characteristics and dietary factors are presented as means ± standard deviations (SD) or numbers (percentages) across weighted quintiles of each dietary score and compared using linear contrast or

https://doi.org/10.1017/S1368980021002871 Published online by Cambridge University Press

Cochran–Mantel–Haenszel tests, depending on the type of variable (continuous or ordinal). For descriptive purposes, nutrient intakes were energy-adjusted using the residual method[38]. Relative difference between lower nutritional quality and higher nutritional quality was computed for descriptive purposes. Tests of statistical significance were two-sided, and the type I error was set at 5 %. Descriptive statistical analyses were performed using SAS software (version 9.3, SAS Institute Inc.).

The Preventable Risk Integrated ModEl (PRIME) was developed by Oxford University[19]. It relates the consumption of food/nutrients components with different risk factors such as blood pressure, serum cholesterol and obesity and subsequent mortality from several causes from non-communicable chronic diseases including CHD, stroke and cancer. The relationships between nutrients/components of the diet and health are derived from scientific published data[19]. A detailed description of the PRIME model can be found elsewhere[19]. The empirical model was calibrated using French health data (cause of death by age and sex categories), using the year 2010 as reference for calibration[39]. The energy-adjusted nutritional variables introduced in the PRIME model were consumption in fruits (mean and SD, percentage of low consumers of fruits), vegetables (mean and SD, percentage of low consumers of vegetables), intakes of fibres (mean and SD), total fat (mean and SD), MUFA (mean and SD), PUFA (mean and SD), SFA (mean and SD), cholesterol (mean and SD), salt (mean and SD) and energy intakes (mean and SD) in a reference situation (corresponding to the median quintile of the dietary indexes) and a counterfactual situation (corresponding to quintile 1 and quintile 5). The differences between the reference and counterfactual situations were used to estimate the number of deaths avoided through the modification of dietary intakes.

A Monte–Carlo procedure using 100·000 replications was used to determine the 95 % uncertainty intervals for the various estimates.

Results

Descriptive statistics

From the 138 000 participants included in the NutriNet-Santé study up to June 2015, we selected those having at least three dietary records (*n* 115 840) during the first 2 years of follow-up – whichever the distribution of dietary records between weekdays and weekend days, excluding 20 037 participants who under-reported their food consumption. After removing some participants with missing data for the computation of weighting, our final population study included 99 641 men and women (see online Supplemental Fig. 1).

The characteristics of the population across weighted quintiles of FSAm-NPS DI are presented in Table 1. A lower quality of the foods consumed measured by the FSAm-NPS DI was associated with male sex, lower age, higher educational level, lower income, smoking and lower physical activity.

The descriptive characteristics across weighted quintiles of other indexes are shown in Supplemental Tables 2–7. Overall, other indexes were associated with socio-demographic characteristics in the same direction, except for educational level which was consistently negatively associated with the nutritional quality of the diet for all scores.

Correlation coefficient between dietary indexes ranged from +0·73 between DQI-I and PANDiet and +0·71 between PANDiet and FSAm-NPS DI to +0·35 between Medi-Lite and FSAm-NPS DI (Table 2). Similarly, weighted Kappa across quintiles of dietary indexes ranged between 0·19 between Medi-Lite and FSAm-NPS DI and 0·52 between DQI-I and PANDiet (Table 3).

Overall, a higher nutritional quality of the diet as reflected by dietary indexes was associated with lower intakes of energy, fats, saturated fats and cholesterol, and higher intakes of fruit and vegetables, fibres and PUFA (Table 4 and see online Supplemental Tables 8–13). For salt, a higher nutritional quality of the diet was associated with a lower intake of salt, except for the Medi-Lite, FSAm-NPS DI and HDI. The magnitude of the differences varied across the dietary indexes. The FSAm-NPS DI displayed the highest cross-quintile differences in energy (relative difference between lower nutritional quality and higher nutritional quality $\Delta = -28{\cdot}0$ %), fat ($\Delta = -9{\cdot}23$ percentage points), saturated fat ($\Delta = -6{\cdot}8$ percentage points) and MUFA intakes ($\Delta = -2{\cdot}8$ percentage points) towards lower intakes; the DQI-I displayed the highest difference in fruit and vegetable intakes between the highest and the lowest quintile ($\Delta = +77{\cdot}8$ % for fruit, $\Delta = +59{\cdot}0$ % for vegetables, respectively).

Preventable Risk Integrated ModEl model simulation

The findings of the PRIME model for overall mortality by dietary indexes are presented in Table 5. Overall mortality was compared between quintiles of dietary indexes, with the lowest quintile representing the lowest nutritional quality and the highest quintile representing the highest nutritional quality.

A modification of dietary intakes from medium quality to very low quality (i.e. from the middle quintile to the quintile with the lowest nutritional quality) was associated with an increased number of deaths ranging from 3485 (95 % uncertainty interval (CI) 4002, 2987) for HDI and 3379 (95 % CI 3881, 2894) for FSAm-NPS DI to 838 (95 % CI 1163, 523) for Medi-Lite. Conversely, a modification of dietary intakes from medium quality to very high quality (i.e. from the middle quintile to the quintile with the highest nutritional quality) was associated with a decrease in the number of deaths ranging from 1995 (95 % CI 1676,

https://doi.org/10.1017/S1368980021002871 Published online by Cambridge University Press

Table 1 Participant characteristics across food standards agency nutrient profiling system dietary index (FSAm-NPS DI) weighted quintiles, NutriNet-Santé cohort*

	Q1 %	Q2 %	Q3 %	Q4 %	Q5 %	P_{trend}†
Quintile cut-offs						
Men	> 8·39	7·05–8·39	5·89–7·05	4·5–5·89	<4·51	
Women	> 8·33	6·91–8·33	5·71–6·91	4·26–5·71	<4·26	
Unweighted	19 925	21 126	20 502	19 740	18 348	
Weighted	19 969·91	19 893·12	19 939·13	19 916·83	19 922·01	
Age (years)						<0·0001
Mean	34·93	41·30	46·03	49·61	51·84	
SD	13·52	14·71	15·36	15·50	15·47	
Women	78·45	78·45	78·4	78·49	78·47	<0·0001
Educational level						<0·0001
<High-school diploma	38·4	44	51·9	57·5	63·9	
High school diploma	23·2	19·5	16·8	15	13·7	
Postgraduate	38·4	36·5	31·3	27·5	22·4	
Occupational status						<0·0001
Unemployed	15	14·8	14·4	12·7	11·7	
Self-employed, farmer	2·1	2·3	1·9	2·1	2·6	
Employee, manual worker	28·9	26·3	24	21	21·8	
Intermediate professions	13·5	13·5	11·8	11	9·6	
Managerial staff, intellectual profession	13·6	14·2	12·5	10·5	8·9	
Student	19·2	12·2	9·2	7·3	6·2	
Retired	7·7	16·7	26·3	35·6	39·2	
Monthly income per household unit						<0·0001
<1200 €	31·2	25	22·3	19·3	21·1	
1200–1800 €	31·7	32·1	32·5	34·5	31·7	
1800–2700 €	22·8	24·1	24·6	24·9	26·8	
>2700 €	14·3	18·8	20·7	21·2	20·5	
Smoking habits						<0·0001
Never smoker	49·1	49·2	49·5	51·2	50·1	
Former smoker	26·5	32·8	36	36·9	40	
Current smoker	24·4	18	14·5	11·8	9·9	
Physical activity‡						<0·0001
High (1)	28·6	31·7	37·5	41·1	45·4	
Moderate (2)	40·5	42·1	40·1	38·7	35·5	
Low (3)	30·9	26·2	22·4	20·2	19	

Q, quintile.
*All values presented are weighted data (unless otherwise specified). Values are means and standard deviation or percentages, as appropriate. For clarity purposes, quintiles were reversed for the FSAm-NPS DI so that quintile 1 refers to lowest nutritional quality of the diet and quintile 5 highest nutritional quality of the diet.
†Linear contrast test for continuous variables or Mantel–Haenszel χ^2 test for categorical variable.
Occupational status: χ^2 test, as the variables were not ordinal.
‡Optional questionnaire, 12 037 missing value.

2299) for PANDiet, 1986 (95 % CI 1565, 2361) for DQI-I, 1931 (95 % CI 1499, 2316) for FSAm-NPS DI and 858 (95 % CI 499, 1205) for HDI (Table 5).

For DQI-I, Medi-Lite and mPNNS-GS, the estimates were of similar magnitude at each end of the spectrum (i.e. from lowest quintile to median *v.* from median to highest quintile of nutritional quality): for DQI-I, the number of deaths from median to lowest quintile increased by 1664 (95 % CI 2101, 1242) *v.* decreased by 1986 (95 % CI 1565, 2361) from median to highest quintile; for Medi-Lite, increased by 838 (95 % CI 499, 1205) *v.* decreased by 1056 (95 % CI 781, 1322); for mPNNS-GS, increased by 2289 (95 % CI 2665, 1920) *v.* decreased by 1863 (95 % CI 1544, 2169).

However, for the HDI and FSAm-NPS DI, the estimated number of deaths at the lower end of the spectrum of the nutritional quality of the diet (i.e. from the lowest quintile to the median quintile) was much higher than at the higher end of the spectrum (i.e. from the median quintile to the highest quintile): for HDI, the number of deaths from median to lowest quintile increased by 3485 (95 % CI 4002, 2987) *v.* decreased by 858 (95 % CI 499, 1205) from median to highest quintile; for FSAm-NPS DI, increased by 3379 (95 % CI 3881, 2894) *v.* decreased by 1931 (95 % CI 1499, 2316).

Overall, modifications of the diet from the lowest nutritional quality to the highest nutritional quality resulted in a higher number of deaths avoided for the FSAm-NPS DI (5310), followed by the HDI (4343) and a lower number for Medi-Lite (1894).

Discussion

Overall, higher dietary indexes led to a significant number of deaths avoided or delayed, but with varying magnitude depending on the index. Among the various dietary indexes that were investigated, the FSAm-NPS DI led to the highest number of deaths avoided when considering impact for both from lower to median and median to higher nutritional quality of the diet, followed by the HDI, the

Public Health Nutrition

https://doi.org/10.1017/S1368980021002871 Published online by Cambridge University Press

Table 2 Nutritional characteristics across food standards agency nutrient profiling system dietary index (FSAm-NPS DI) weighted quintiles, NutriNet-Santé cohort*

	Q5		Q4		Q3		Q2		Q1		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P*†
Energy intake (kcal/d)	2035·17	537·23	1923·61	449·87	1848·42	439·50	1759·53	449·79	1589·81	438·96	<0·0001
Alcohol (g/d)	8·14	13·24	7·96	11·36	8·03	11·68	7·18	10·41	5·00	9·20	<0·0001
Proteins											
%‡	15·66	2·87	17·01	2·90	17·97	3·11	18·86	3·79	21·02	5·52	<0·0001
Cholesterol (g/d)	327·60	103·47	320·60	96·96	316·35	95·75	306·79	107·47	294·18	123·57	<0·0001
Carbohydrates											
%‡	41·29	6·17	42·09	5·89	42·72	5·97	43·57	6·61	44·97	8·13	<0·0001
Lipids											
%‡	42·80	5·14	40·61	4·79	39·00	4·92	37·21	5·40	33·57	6·55	<0·0001
SFA											
%‡	18·69	2·94	17·07	2·57	15·86	2·45	14·48	2·56	11·89	3·02	<0·0001
MUFA											
%‡	15·76	2·72	15·13	2·66	14·66	2·84	14·17	3·23	12·98	3·71	<0·0001
PUFA											
%‡	5·45	1·68	5·50	1·64	5·54	1·69	5·62	1·93	5·74	2·08	<0·0001
n-3 PUFA (g/d)	1·03	0·52	1·21	0·55	1·33	0·64	1·46	0·75	1·64	0·89	<0·0001
n-6 PUFA (g/d)	9·29	3·73	9·29	3·38	9·33	3·39	9·40	3·63	9·52	3·71	<0·0001
Fruits (g/d)	92·96	92·03	144·25	99·91	177·77	114·14	215·96	133·53	270·91	173·87	<0·0001
Vegetables (g/d)	140·92	83·04	183·35	85·72	209·34	92·48	236·67	100·97	291·74	147·17	<0·0001
β-Carotene (μ/d)	2227·62	1697·4	2849·16	1768·3	3201·48	1862·7	3590·31	2050·7	4493·19	3202·7	<0·0001
Ca (mg/d)	838·91	247·37	880·89	214·28	904·22	214·77	923·04	222·25	977·67	254·14	<0·0001
Fe (mg/d)	11·20	3·45	12·24	3·16	12·89	3·13	13·57	3·54	14·82	4·14	<0·0001
Fibres (g/d)	13·90	3·83	16·69	3·90	18·54	4·32	20·56	5·02	24·09	7·18	<0·0001
Salt (g/d)	8·29	2·23	8·60	1·97	8·64	1·91	8·76	1·94	8·66	2·09	<0·0001
Folates (mg/d)	251·78	72·78	290·77	73·26	313·13	76·44	337·26	85·16	384·87	112·89	<0·0001
Vitamin C (mg/d)	88·99	60·43	104·21	67·75	109·24	56·41	117·46	58·48	133·29	69·64	<0·0001
Vitamin E (mg/d)	10·55	3·86	11·09	3·52	11·36	3·56	11·86	3·86	12·49	3·98	<0·0001

*Values are means (standard deviations). For clarity purposes, quintiles were reversed for the FSAm-NPS DI so that quintile 1 refers to lowest nutritional quality of the diet and quintile 5 highest nutritional quality of the diet.
†*P* estimated by linear contrast using ANOVA.
‡% of daily energy intake without alcohol intake.

Table 3 Spearman correlation coefficients between dietary scores, partial on energy intake

	DQI	AHEI	Medi-Lite	PANDIET	HDI	FSAm-NPS DI	mPNNS-GS
DQI	1	0·52	0·46	0·73	0·5	0·61	0·65
AHEI	0·52	1	0·67	0·51	0·5	0·48	0·54
Medi-Lite	0·46	0·67	1	0·4	0·48	0·35	0·43
PANDIET	0·73	0·51	0·4	1	0·52	0·71	0·62
HDI	0·5	0·5	0·48	0·52	1	0·43	0·43
FSAm-NPS DI	0·61	0·48	0·35	0·71	0·43	1	0·52
mPNNS-GS	0·65	0·54	0·43	0·62	0·43	0·52	1

AHEI, alternate healthy eating index; DQI-I, diet quality index-international; FSAm-NPS DI, food standards agency nutrient profiling system dietary index; HDI, healthy dietary indicator; Medi-Lite, literature-based adherence score to Mediterranean diet; PANDiet, probability of adequate nutrient intake dietary score; PNNS-GS, programme national nutrition santé guideline-score.
For clarity purposes, ranking in the FSAm-NPS DI was reversed so that lower scores reflected lower nutritional quality of the diet and higher scores higher nutritional quality of the diet, as for other dietary indexes.

Table 4 Weighted κ coefficient across quintiles of scores

	DQI	AHEI	Medi-Lite	PANDIET	HDI	FSAm-NPS DI	mPNNG-GS
DQI	1	0·36	0·29	0·52	0·35	0·42	0·41
AHEI	0·36	1	0·47	0·34	0·35	0·33	0·34
Medi-Lite	0·29	0·47	1	0·26	0·35	0·19	0·25
PANDIET	0·52	0·34	0·26	1	0·35	0·46	0·37
HDI	0·35	0·35	0·35	0·35	1	0·30	0·26
FSAm-NPS DI	0·42	0·33	0·19	0·46	0·30	1	0·32
mPNNG-GS	0·41	0·34	0·25	0·37	0·26	0·32	1

AHEI, alternate healthy eating index; DQI-I, diet quality index-international; FSAm-NPS DI, food standards agency nutrient profiling system dietary index; HDI, healthy dietary indicator; Medi-Lite, literature-based adherence score to Mediterranean diet; PANDiet, probability of adequate nutrient intake dietary score; PNNS-GS, programme national nutrition santé guideline-score.
For clarity purposes, ranking in the FSAm-NPS DI was reversed so that lower scores reflected lower nutritional quality of the diet and higher scores higher nutritional quality of the diet, as for other dietary indexes.

Table 5 Number of deaths avoided (an 95 % uncertainty interval) for change from a reference diet corresponding to Q3 of each score to a counterfactual diet corresponding to Q1, Q2, Q4 and Q5 of each score

	Q3–Q1*		Q3–Q2*		Q3–Q4*		Q3–Q5*	
	n	95 % uncertainty interval	*n*	95 % uncertainty interval	*n*	95 % uncertainty interval	*n*	95 % uncertainty interval
DQI	−1664	−2101, −1242	−1042	−1236, −850	962	800, 1118	1986	1565, 2361
FSAm-NPS DI	−3379	−3881, −2894	−980	−1132, −828	859	708, 1004	1931	1499, 2316
AHEI	−2637	−3057, −2228	−857	−996, −718	657	546, 766	1570	1305, 1824
Medi-Lite	−838	−1163, −523	−277	−407, −149	685	560, 807	1056	781, 1322
PanDIET	−1031	−1407, −672	−748	−891, −606	784	668, 898	1995	1676, 2299
HDI	−3485	−4002, −2987	−1343	−1550, −1138	214	9, 416	858	499, 1205
mPNNS-GS	−2289	−2665, −1920	−1433	−1661, −1206	809	660, 955	1863	1544, 2169

AHEI, alternate healthy eating index; DQI-I, diet quality index-international; FSAm-NPS DI, food standards agency nutrient profiling system dietary index; HDI, healthy dietary indicator; Medi-Lite, literature-based adherence score to Mediterranean diet; PANDiet, probability of adequate nutrient intake dietary score; PNNS-GS, programme national nutrition santé guideline-score.
*For FSAm-NPS DI, the quintiles were reversed so that Q1 corresponds to lower nutritional quality of the diet and Q5 higher nutritional quality of the diet.

Alternative Healthy Eating Index, the mPNNS-GS, the DQI-I, the PANDiet and, finally, the Medi-Lite. While the association between adherence to these indexes and mortality onset in observational studies has been investigated[40], to the best of our knowledge, this study is the first to estimate the impact on mortality from nutrition-related diseases associated with multiple dietary indexes in the same sample from the general population (here applied to the French general population).

Overall, these results are consistent with cohort studies evidencing the association between the various dietary indexes and all-cause mortality. A recent umbrella review of meta-analyses of the association between adherence to the Mediterranean diet and mortality has concluded to a 'highly suggestive' evidence for a decreased risk of overall mortality for subjects with a higher adherence to the Mediterranean diet, but only based on cohort studies (RR = 0·91, 95 % CI 0·89, 0·93); evidence was considered 'suggestive' for the reduction in cancer mortality from one meta-analysis. However, results from meta-analyses based on randomised trials did not yield significant evidence of a reduction of risk of overall or cardiovascular mortality. Moreover, the method used to quantify adherence to the Mediterranean diet varied across studies, and

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the Medi-Lite was not the preferred measure. In a meta-analysis of cohort studies, the DQI-I was significantly associated with a reduction in cancer mortality (HR: 0·91; 95 % CI 0·89, 0·93, $I^2 = 0{\cdot}0\,\%$)[41]. As to other indexes, the literature is somewhat scant on their association with mortality[42], though significant reductions in the onset of NCD (CVD and cancer in particular) have been observed[43–47].

A recent analysis using the PRIME model investigated the impact on mortality of adherence to dietary recommendations in the Swedish population – using the Nordic Nutrition Recommendations – and estimated that 6405 (95 % CI 5086, 7086) would be avoided by adhering to recommendations, an estimate higher to any of those in the current analysis. However, the counterfactual scenario involved in this study explored the impact of reaching all dietary recommendations in the overall population[48]. Another study by Egnell *et al.* estimated at 7680 (95 % CI 6636, 8732) the number of deaths delayed or avoided by using the Nutri-Score (which is underpinned by the FSAm/HCSP score) in the French population[49]. The counterfactual scenario in this case was built on the results from an experimental study[6]. The difference in magnitude of effects between these studies may be related to the use of more hypothetical data to base the counterfactual scenario, which may be more optimistic to achieve, while we used observed dietary behaviour.

Beyond the sole numbers, the balance of deaths avoided between the high end (healthier diet) or the low end (less healthy diet) of the spectrum of each index appears of importance. Indeed, while some indexes display balanced numbers at each side of the spectrum (DQI-I, Medi-Lite and mPNNS-GS dietary indexes), others tended to be more effective either at the high (PANDiet) or the low (FSAm-NPS DI, HDI) end of the spectrum. This suggests that some guidelines may lead to higher health benefits for subjects with less healthy diets, while others rather lead to benefits for subjects with already healthy diets. This finding appears of importance but needs to be confirmed with studies investigating specifically the effects of dietary indexes in vulnerable populations.

Indeed, less healthy diets are usually associated with specific sociodemographic factors, such as lower levels of education, lower incomes and higher levels of smoking, as evidenced in this study. Such differences contribute to the definition of health inequalities, which are therefore mirrored in nutrition.

Such inequalities are also reflected in other risk factors such as physical activity behaviour, as lower socio-economic groups tend to be less physically active[50]. Overall, nutritional risks therefore tend to be clustered among more disadvantaged groups[51], which suggests that diet may be one of the key mediators of the relationship between socio-economic position and mortality[52,53].

Indeed, given this clustering of risk factors, low socio-economic groups tend to have higher levels of mortality and premature mortality[54], in particular from NCD[55]. In France, the difference in life expectancy at 35 years of age between blue and white collar workers is on average 6 years[56]. Mortality from myocardial infarction was estimated at 51 % higher in France in the most disadvantaged groups compared with the most advantaged in 2011[57].

Given this worrying situation, tackling inequalities in health and nutrition has become one of the major challenges for public health authorities. However, nutrition interventions have varying impacts on health inequalities. For example, the dissemination of nutrition information, through dietary guidelines, has been suggested to rather widen inequalities, as more health conscious groups (therefore usually with healthier diets and higher socio-economic backgrounds) are more likely to adhere to the disseminated recommendations compared with lower socio-economic groups[58,59].

Our results suggest that using some dietary profiles to underpin nutrition strategies – using *a priori* dietary indexes – may unfavourably impact health inequalities (PANDiet), by benefiting principally at the high end of the dietary spectrum, i.e. in subjects with healthier diets, who are more likely to belong to more advantaged groups, while others may on the contrary contribute to the reduction of inequalities (FSAm-NPS DI, HQI), by benefiting principally at the lower end of the dietary spectrum, i.e. in subjects with poor diets, who are more likely to belong to disadvantaged groups. Considering these findings, the FSAm/HCSP, which is used as the underlying nutrient profiling system for the French front-of-pack labelling system Nutri-Score, would appear as a valid choice in the optic of reducing inequalities. Overall, these findings appear of major importance when considering using such profiles as bases for nutrition-related policies (dietary guidelines, health promotion campaigns for example).

Our results need to be interpreted in the light of the dietary components that contribute to the PRIME model. Indeed, the structure of the macro-simulation model may also in part explain our results. The components taken into account in the PRIME model include energy, total fat, SFA, PUFA, MUFA, cholesterol, salt, fibres and fruit and vegetables. Among the dietary indexes included in our study, the FSAm-NPS DI is the one which takes into account the most important number of these components within its computation, and for which the differences between quintiles were highest. Therefore, its relatively high performance within the PRIME model may also be related to the consistency between the approaches taken in the computation. Of note, both the FSAm-NPS of foods and the PRIME model were developed by the Nuffield Department of Population Health in Oxford, which may partly explain the consistency of approaches in the models. For other indexes, the components included in the PRIME model are more likely to be proxy measures of components of the index. For the PANDiet for example, which includes several adequacy components for several vitamins and mineral, these components are only reflected in the fruits and vegetables

https://doi.org/10.1017/S1368980021002871 Published online by Cambridge University Press

components of the PRIME model, therefore limiting their contribution to the estimates of deaths avoided or delayed in the macro-simulation.

This highlights some of the limitation of the PRIME model to adequately assess each of the dietary indexes. However, the PRIME model builds upon the most documented evidence of the association between nutritional factors and mortality, principally from meta-analyses, and the lack of conclusive estimates for the association between each of the index components and mortality is likely to be the most important limitation for their inclusion in the simulation model.

The main strength of our study resides in the computation of multiple dietary indexes, encompassing various approaches to qualify the nutritional quality of the diet, and investigating their potential impact on nutrition-related mortality. The dietary data used to compute each of the indexes are of high quality, as it was derived from repeated 24 h records (with a median number of six records per participant), therefore providing particularly accurate estimates of the intakes of each of the components.

Our study is subject to some limitations. The NutriNet-Santé study is a cohort study including volunteer participants from the general population. Therefore, they may be more health conscious, with an overall higher nutritional quality of the diet. However, results were weighted using census data, which has been found to be an adequate method to reduce selection bias[60]. Moreover, though this bias may limit the interpretation of the mortality estimates we generated, it would not impact the comparison across dietary indexes. Another limitation pertains to the use of self-reported data for dietary intake, which is prone to under-reporting and misestimating of consumed portion size, with some selectivity as energy-dense foods are more likely to be under-reported. Though validated algorithms were used to exclude under-reporters, it is likely that some misclassification bias or error remain, leading to potential under-estimation of the absolute number of deaths avoided or delayed.

In conclusion, our results provide some insights as the importance of an overall healthier diet following dietary guidelines to reduce mortality from nutrition-related diseases. It also points towards dietary indexes that may be potentially more efficient in groups with less healthy diets, and which could participate in reducing social inequalities in nutrition when used to underpin nutrition policies. Future studies should investigate the potential health gains associated with various dietary indexes in different groups of the population in order to confirm the present results.

Acknowledgements

Acknowledgements: We thank Younes Esseddik (IT manager); Thi Hong Van Duong, Régis Gatibelza and Jagatjit Mohinder (computer scientists); Fabien Szabo de Edelenyi, PhD (data management supervisor); Julien Allègre, Nathalie Arnault, Laurent Bourhis (data-managers/biostatisticians); Fatoumata Diallo, MD, Sandrine Kamdem, MD and Roland Andrianasolo, MD (physicians); Nathalie Druesne-Pecollo, PhD (operational coordination) for their technical contribution to the NutriNet-Santé study. We thank all the volunteers of the NutriNet-Santé cohort. *Financial support:* The NutriNet-Santé study was supported by the following public institutions: Ministère de la Santé, Santé Publique France, Institut National de la Santé et de la Recherche Médicale (INSERM), Institut national de recherche pour l'agriculture, l'alimentation et l'environnement (INRAe), Conservatoire National des Arts et Métiers (CNAM) and Université Sorbonne Paris Nord. Researchers were independent from funders. Funders had no role in the study design, the collection, analysis and interpretation of data, the writing of the report and the decision to submit the article for publication. K.A. and M.A. were funded by a doctoral grant from Université Paris 13. *Conflict of interest:* The authors declare that they have no conflict of interest. *Authorship:* C.J., P.L., M.A., K.A., M.T., S.H., L.-G.S. and E.K.-G. C.J., E.K.-G., L.-G.S. and P.L. conceptualised the project and supervised data analyses and interpretation. E.K.G. performed data analyses for the NutriNet-santé cohort study. P.L. performed data analyses for the PRIME simulations. C.J. drafted and revised the paper. All authors interpreted the data and critically revised the manuscript for important intellectual content. All authors had full access to all of the data in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis. All authors have read and approved the final manuscript. *Ethics of human subject participation:* This study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving study participants were approved by the ethics committee of the French Institute for Health and Medical Research (IRB INSERM n° 0000388FWA00005831) and by the National Commission on Informatics and Liberty (CNIL n° 908450 and n° 909216). The provision of informed consent and an electronic signature is mandatory for enrolment. The NutriNet-Santé study is registered in ClinicalTrials.gov (NCT03335644).

Supplementary material

To view supplementary material for this article, please visit https://doi.org/10.1017/S1368980021002871

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