Potential impact of gradual reduction of fat content in manufactured and out-of-home food on obesity in the United Kingdom: a modeling study

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ABSTRACT

Background: Manufactured and out-of-home foods contribute to excessive calories and have a critical role in fueling the obesity epidemic. We propose a 20% fat reduction in these foods.

Objectives: To evaluate the potential impact of the proposed strategy on energy intake, obesity and related health outcomes in the population.

Methods: We used the National Diet and Nutrition Survey rolling program (NDNS RP) data to calculate fat and energy contributions from 46 manufactured and out-of-home food categories. We considered a gradual fat reduction—focusing on SFA—in these categories to achieve a 20% reduction in 5 years. We estimated the reduction in energy intake in the NDNS RP population and predicted the body weight reduction using a weight loss model. We scaled up the body weight reduction to the UK adult population. We estimated reductions in overweight/obesity and type 2 diabetes cases. We calculated the reductions of LDL, ischemic heart disease (IHD), and stroke deaths that could be prevented from the SFA reduction.

Results: The selected categories contributed to 38.6% of the population's energy intake. By the end of the fifth year, our proposed strategy would reduce the mean energy intake by 67.6 kcal/d/person (95% CI: 66.1–68.8). The energy reduction would reduce the mean body weight by 2.7 kg (95% CI: 2.6–2.8). The obesity prevalence would be reduced by 5.3% and the overweight prevalence by 1.5%, corresponding to 3.5 and 1 million cases of obesity and overweight, respectively, being reduced in the United Kingdom. The body weight reduction could prevent 183,000 (95% CI: 171,000–194,000) cases of type 2 diabetes over 2 decades. Energy from SFA would fall by 2.6%, lowering LDL by 0.13 mmol/L and preventing 87,560 IHD deaths (95% CI: 82,260–112,760) and 9520 stroke deaths (95% CI: 4400–14,660) over 20 years.

Conclusions: A modest fat reduction (particularly in SFA) in widely consumed foods would prevent obesity, type 2 diabetes, and cardiovascular disease. *Am J Clin Nutr* 2021;113:1312–1321.

Keywords: saturated fat, total fat, reformulation, food energy-density, LDL, obesity, overweight

Introduction

Globally, 39% of the adult population is overweight and 13% is obese (1). In the United Kingdom, 35% of adults are overweight and 29% are obese (2). Although obesity and overweight are due to a variety of factors—ranging from genetic and psychological to social and environmental ones—the food environment, and in particular the nutritional quality of the food supply, plays a major role in their onset (3). Most of the world population has progressively changed its dietary habits by cooking less, eating out more often, and relying more on products that require minimal or no preparation (4–6). Evidence shows that eating out is associated with higher energy intake, and that—when assessed through the nutrient profiling model used by the UK government—manufactured and out-of-home products have excessive amounts of total fat and SFA, have high energy density (i.e., amount of kilocalories for 100 g of product), and are low in dietary fiber (7–9).

Recently, the UK Scientific Advisory Committee on Nutrition (SACN) issued new recommendations stating that population SFA intake should be lowered to around 10 percent of dietary energy (%E) and that the government should consider strategies

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Abbreviations used: %E, percentage of dietary energy; DLW, doubly labeled water; IHD, ischemic heart disease; NDNS RP, National Diet and Nutrition Survey rolling program; SACN, Scientific Advisory Committee on Nutrition.

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to reduce SFA intake at the population level (10). The new recommendations are based on the evidence that reducing SFA lowers serum total and LDL cholesterol and improves indicators of glycemic control, therefore reducing the risk of ischemic heart disease (IHD) and stroke (10). Similarly, the recent WHO draft guidelines recommend that SFA intake should be reduced to less than 10%E, particularly in individuals whose SFA intake exceeds 10%E (11). According to the National Diet and Nutrition Survey rolling program (NDNS RP) years 2014–2016, SFA intake in the UK population is high, as the average %E from SFA is 12.5%E and exceeded 14.5%E in individuals aged 75 and over (12). These figures would have underestimated the true intakes, as evidence suggests that underreporting occurs more frequently for high-fat foods (13–15).

The latest NDNS RP data also show that the average fiber intake in people aged 19–64 years was 19 g/day and that only 9% of people in this age group met the recommendation of consuming 30 g of fiber per day (12). The latest SACN recommendation is based on the evidence that diets higher in dietary fiber are associated with lower incidences of cardiovascular diseases, coronary events, type 2 diabetes, and colorectal cancer (16). Evidence suggests that fiber dilutes food energy density, and it has a beneficial effect on satiety and appetite regulation (17).

Compared to all the other nutrients, fat is very energy dense, providing 9 kcal/g. A small reduction of fat content in food products and a concurrent increase in fiber-rich ingredients could be an effective strategy for reducing food energy density and, therefore, population energy intake, overweight, and obesity. In this study, we propose a fat reformulation strategy consisting of a gradual and stepwise reduction of fat (preferably SFA) by 20% in manufactured and out-of-home food consumed in the United Kingdom. The primary objective of this study is to quantify the potential impacts of the proposed fat reformulation strategy on population energy intake, overweight, and obesity in the UK adult population. The secondary objectives of the study are to quantify the impact of our strategy on population LDL cholesterol and to forecast the cases of type 2 diabetes, IHD, and stroke that could be prevented by reducing BMIs and average LDL cholesterol levels in the UK population.

Methods

We propose a reduction of food energy density through a reduction of fat content in 46 manufactured and out-of-home food categories. The goal is to achieve a 20% reduction in fat (preferentially SFA) in 5 years, with a yearly reduction of ≈4%. To minimize changes in portion sizes, fiber-rich ingredients would be used to replace SFA. Based on the food consumption data from each participant of the NDNS RP for years 7 and 8 (2014/15–2015/16), we estimated the potential impact of this proposed strategy on energy and fat intakes at the population level. This modeling method has previously been used to evaluate the impact of a 40% reduction of sugar in soft drinks (18).

Data sources and scenarios

We used the data from the NDNS RP, which includes self-reported information on foods, nutrient intakes, and sociodemographic information, such as age and total household income in the last 12 months, in a representative sample of the UK population ($n = 2723$). The NDNS RP also includes body weight and height data measured by NDNS RP field workers (12). Our proposed strategy models the intake of most of the NDNS RP food categories (19). We included all the NDNS RP food categories coded as "manufactured and out-of-home," including the beans and meat alternatives categories, in which intake data were aggregated with the homemade data. We excluded all homemade food categories and all the minimally processed food categories typically used to prepare homemade meals, such as bread, milk, fresh meats, grain products, oils and fats, pulses, nuts, fruit, and vegetables. We also excluded all drinks, such as sugar-sweetened drinks, alcoholic drinks, and fruit juices. We excluded nutrition supplements.

Modeling

We calculated the calories from the selected food categories in the diets of the whole NDNS RP population. We then ranked the food categories according to the calories provided to the whole NDNS RP population. We did the same for fat and SFA. We also calculated the percentage of participants consuming each food category. We then calculated the baseline data (calories, fat, and SFA) for each food category for each NDNS RP individual. **Figure 1** summarizes the main steps of the modeling strategy. Since a large body of evidence shows that underreporting is frequent in self-reported food intake studies (14, 15), we used the estimates provided by the NDNS RP doubly labeled water (DLW) sub-study to adjust our baseline estimates. According to the DLW study, which used an established method generally agreed to be the most accurate for detecting misreporting of energy intake, survey participants underreport, on average, 27% of their energy and nutrient intakes (20). We therefore multiplied energy and nutrient intakes by 1.27 so that our baseline estimates could be closer to the real energy and nutrient intakes.

Using the adjusted baseline data for each food consumed within the selected food category by each participant, we generated a 20% fat reduction with a constant yearly proportional decrease (corresponding to a 4.4% annual reduction) over 5 years. We operated the fat reduction in each single food (e.g., chocolate cookie) included in the selected food category (i.e., cookies category). The fat reduction was carried out predominantly by a reduction of SFA content. However, for a few products (e.g., potato snacks) that are relatively high in fat but low in SFA, we firstly reduced the SFA and then, when there was no SFA left in the food, we reduced the rest of the remaining fat. We then calculated the energy intake reduction arising from the reduction in fat intake for each NDNS RP participant.

We assumed that the quality and the quantity of food intake (and therefore also the food purchased) for each participant would not change during the implementation period. To avoid changes in portion size (i.e., to keep products' weights unchanged), we assumed that manufacturers would gradually replace fat with fiber-rich ingredients, such as vegetables or legumes, or use category-specific technologies to reduce fat (21). We calculated the predicted mean reduction in calorie intake at the end of each year for the entire NDNS RP population and for each income and age group. We obtained CIs for the generated means through the bootstrapping method (22).

To determine the impact of reduced energy intake on body weight, we calculated the expected change in steady-state body

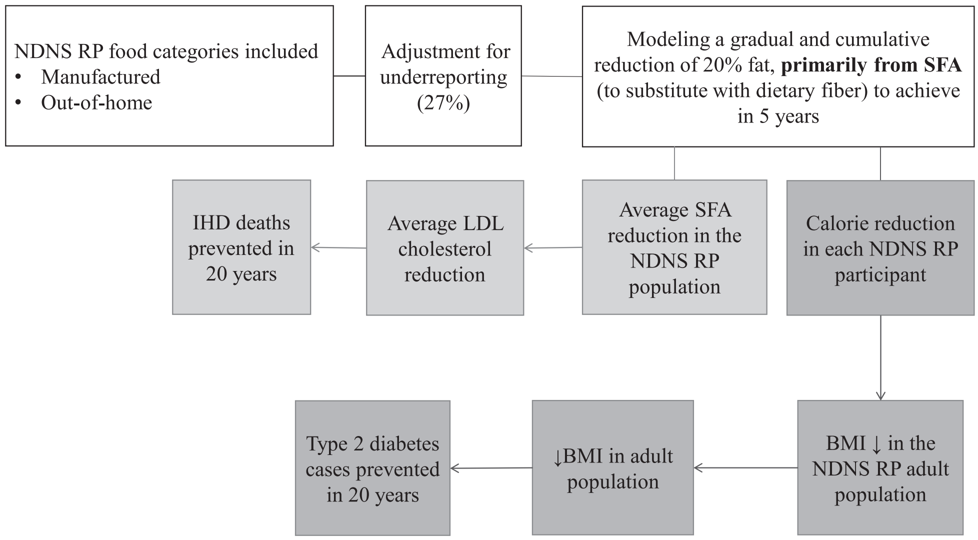

FIGURE 1 Summary of different steps of the modeling strategy. Abbreviations: IHD, ischemic heart disease; NDNS RP, National Diet and Nutrition Survey rolling program.

weight for each adult (defined as older than 18 years) at an individual level using the mathematical model proposed by Hall and Jordan (23). The model takes into account the dynamic physiological adaptation to changes in body weight and has been externally validated; the predicted change in body weight from the Hall and Jordan (23) model closely matches the weight loss results observed in several long-term intervention studies ($r = 0.983$). We applied the model to each adult in the NDNS RP, taking into account the age, sex, weight, height, and level of physical activity of each individual. A detailed description of the modeling procedure has been reported in our previous study (18). After calculating the weight loss for each individual, we calculated the new BMI and the changes in the prevalence of obesity and overweight corresponding to the 20% fat reduction of the fifth year of the strategy. As the last step, we scaled up the calculated prevalence of obesity and overweight to the whole UK adult population. We then calculated the number of overweight and obese cases that could be prevented nationwide if the strategy would be implemented. We obtained the estimates of the mid-year UK population size in 2018, which was 66.5 million, from the Office for National Statistics website (24). To predict the number of obesity-related type 2 diabetes cases that would be prevented, we used the calculation from Wang and colleagues (25), whereby a 1% reduction in BMI across the entire UK population would prevent 191,000 (95% CI: 178,000–202,000) incident type 2 diabetes cases over the next 2 decades after the predicted reduction in bodyweight is achieved. This estimation was simulated by creating virtual UK individuals based on the projected BMI distribution, and the risk of developing type 2 diabetes was simulated as a function of age, sex, and BMI (25).

We calculated the %E from fat and from SFA before and after the implementation of our proposed strategy. We determined the resulting change in LDL cholesterol from SFA reduction using the published association by Yu-Poth and colleagues (26), where a reduction of 1% in energy from SFA decreases serum LDL cholesterol by 0.05 mmol/L. We estimated the relative risk reductions for IHD and stroke corresponding to this LDL cholesterol change using the proportional relationship between LDL cholesterol and the risks of these disorders, as reported by Law and colleagues (27, 28): for IHD $(1-0.39)^{(\text{Change in LDL cholesterol}/1.8)}$ and for stroke $(1-0.83)^{(\text{Change in LDL cholesterol}/1.8)}$. We calculated the number of IHD and stroke deaths which would be avoided in the United Kingdom through our strategy, by multiplying the number of yearly IHD and stroke deaths (29) by the corresponding risk reductions.

Statistical analyses

We reported means and 95% CIs where appropriate. We calculated 95% CIs using the bootstrapping method (resampling 1000 times), because it provides robust estimates even when data are skewed (22). We calculated the predicted reduction in energy intake by using STATA version 15 (StataCorp LLC) and built the body weight reduction model in R version 3.6.1 (R Foundation for Statistical Computing). To assess whether there was a statistically significant difference in body weight reduction and energy intake between different income groups, we used the nonparametric Kruskal-Wallis rank sum test.

Sensitivity analyses

To test the robustness of the predicted changes in body weight, we used 2 alternative methods to calculate the change in body weight arising from the reduction in energy intake. First, we used the "3500 kcal = 1 lb rule" (23). According to this method, which does not take into account important individual variables such as sex and initial body weight, a cumulative energy intake deficit of 3500 kcal would result in a reduction in body weight of 1 lb (i.e., 0.45 kg). Second, we used the model proposed by Christiansen and Garby (30), which has been used elsewhere to assess weight changes from energy reductions in studies conducted in the United Kingdom.

TABLE 1 National Diet and Nutrition Survey rolling program food categories included in the strategy, ranked according to their contribution to total calorie intake in the sampled population ($n = 2371$)

Ranking	NDNS RP food category	Total kcal provided in NDNS RP population, by category	Share of consumers, %
1	Cookies, manufactured/retail	169,630	68
2	Buns, cakes, & pastries, manufactured	129,283	46
3	Chocolate confectionery	112,167	50
4	Fried potatoes purchased, including takeaway	110,727	48
5	Potato chips and savory snacks	100,919	55
6	Pizza	97,501	24
7	High-fiber breakfast cereals	95,782	44
8	Savory sauces, pickles, gravies, & condiments	93,771	94
9	Cheddar cheese	91,283	54
10	Other sausages, including homemade dishes	68,504	39
11	Other breakfast cereals (not high fiber)	66,605	37
12	Manufactured, coated chicken/turkey products	61,247	26
13	Manufactured meat pies and pastries	52,562	17
14	White fish coated or fried	46,037	24
15	Ice cream	44,752	27
16	Other cheese	38,390	36
17	Burgers and kebabs purchased	34,112	14
18	Sugar confectionery	32,741	26
19	Pasta, manufactured products & ready meals	26,395	12
20	Other manufactured potato products, fried/baked	21,515	15
21	Manufactured chicken products, including ready meals	17,895	14
22	Fromage frais and dairy desserts, manufactured	17,183	17
23	Beans and pulses, including ready meal & homemade dishes	16,804	19
24	Sweet spreads, fillings, and icing	14,878	12
25	Soup, manufactured/retail	13,165	19
26	Manufactured beef products, including ready meals	13,081	6
27	Other meat products, manufactured, including ready meals	12,590	10
28	Cereal-based milk puddings, manufactured	12,160	12
29	Other cereal-based puddings, manufactured	11,284	5
30	Manufactured canned tuna products, including ready meals	8902	12
31	Manufactured egg products, including ready meals	8515	5
32	Manufactured oily fish products, including ready meals	7689	6
33	Rice, manufactured products & ready meals	7474	4
34	Fruit pies, manufactured	6183	3
35	Meat alternatives, including ready meals & homemade dish	5745	5
36	Other potato products & dishes, manufactured	4462	5
37	Other manufactured vegetable products, including ready meals	4307	4
38	Liver and dishes	3982	3
39	Sponge puddings, manufactured	3521	2
40	Manufactured pork products, including ready meals	2789	3
41	Manufactured lamb products, including ready meals	1636	1
42	Cottage cheese	1165	1
43	Manufactured white fish products, including ready meals	1088	1
44	Manufactured shellfish products, including ready meals	1069	1
45	Ready meals based on sausages	1039	>1
46	Ready meals based on bacon and ham	136	>1

The fourth column shows the percentage of consumers in each category. Abbreviation: NDNS RP, National Diet and Nutrition Survey rolling program.

Results

Table 1 shows the ranking of the manufactured and out-of-home food categories according to their calorie contribution to the diet of the whole NDNS RP population and their relative percentage of consumers. Cookies, cakes, chocolate confectionery, fried potatoes, and potato categories ranked as top contributors to energy intake and were widely consumed (Table 1). The cheddar cheese category ranked as the top contributor to SFA and fat intake, followed by cookies and chocolate confectionery (**Supplementary Tables 1** and **2**). On average, the 46 food categories included in the strategy contributed to 38.6% of the energy intake of the NDNS RP participants (**Figure 2**). In the age groups of 6–11 and 12–18 y, the selected categories contributed to 47.3% and 45% of the total energy intake, respectively (Figure 2). At the end of the fifth year, the mean energy intake reduction would be 67.6 kcal/d/person (95% CI: 66.1–68.8; **Table 2**). Energy intake in those 11–18-year-olds would be reduced by 85.1 kcal/d/person (95% CI: 81.6–88.7), while in the 26–35-year-old age group,

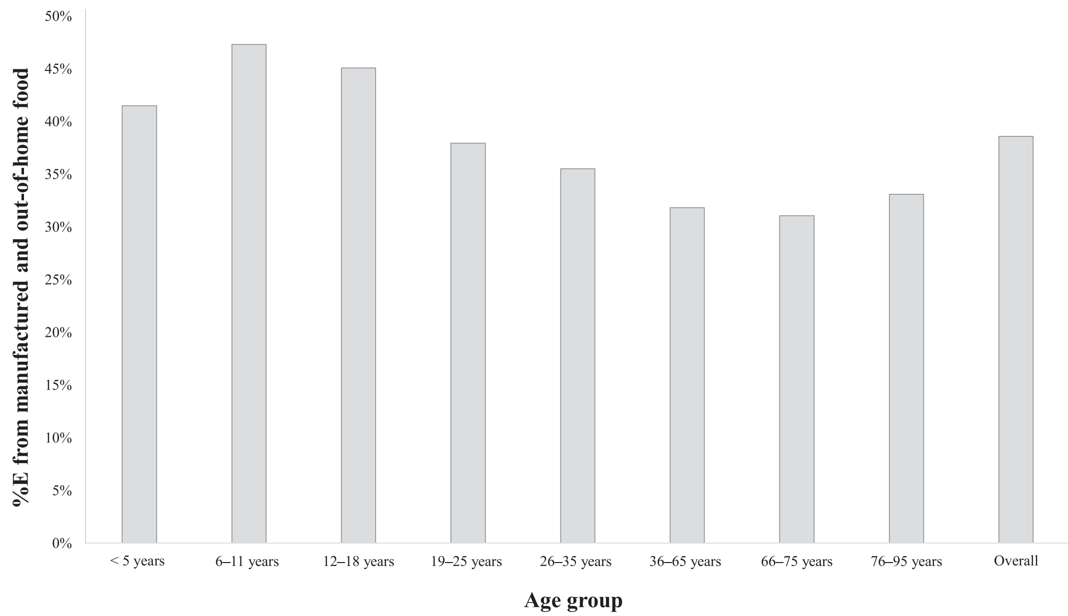

FIGURE 2 Mean %E from the 46 food categories included in the strategy, by age group. Abbreviations: %E, percentage of total energy.

energy intake would be reduced by 76.6 kcal/d/person (95% CI: 71.0–82.3; **Table 3**). The predicted mean reductions of body weight and energy intake at the end of the fifth year did not vary between the different income groups ($P = 0.494$ and $P = 0.496$, respectively; **Supplementary Table 3**).

The predicted reduction in energy intake would lead to a gradual reduction in body weight in the long term. The average reduction in steady-state body weight in adults is predicted to be 2.7 kg (95% CI: 2.6–2.8; Table 2). When we used the "3500 kcal = 1 lb" rule, the average reduction in body weight at the end of the fifth year would be 3.3 kg (95% CI: 3.2–3.4). Alternatively, when we used the model proposed by Christiansen and Garby (30), the average reduction at the end of the fifth year would be 3.5 kg (95% CI: 3.2–3.7). In the NDNS RP population, the average body weight reduction of 2.7 kg would reduce the prevalence of overweight by 1.5 percentage points (from 36.7% to 35.2%) and the prevalence of obesity by 5.3 percentage points (from 29.9% to 23.2%). This reduction would amount to approximately 1 million cases of overweight and 3.5 million cases of obesity being reduced in the UK population. The average BMI of the UK adult population is predicted to be reduced by 0.96 kg/m^2 (from 27.44 kg/m^2 to 26.48 kg/m^2). According to the calculations by Wang and colleagues (25), our predicted BMI reduction could, in turn, prevent 183,000 (95% CI: 171,000–194,000) incident cases of type 2 diabetes over 20 years (i.e., roughly 9100 per year).

At the end of the fifth year, the %E from fat would fall from 33.5% to 31.2%, resulting in an average reduction of 7.5 g/d/person in fat consumption. The amount of fat reduced per 100 g of product varied considerably; for sauces and chocolate confectionery, the fat reduction would be around 6.5 g, while in cookies and sausages the reduction would be around 3.5g (**Figure 3**). In the NDNS RP population, SFA intake as %E would be reduced from 12.7% to 10.1%, resulting in an average SFA reduction of 6.7 g/d/person (95% CI: 6.5–6.9).

According to the regression coefficient published by Yu-Poth and colleagues (26), a reduction of 1% in energy from SFA would result in a decrease in serum LDL cholesterol of 0.05 mmol/L. Our strategy—which would lead to an average reduction of 2.6%E from SFA—would reduce the population average LDL cholesterol by 0.13 mmol/L. According to the estimations by Law and colleagues (27), a 1.8 mmol/L reduction in LDL would reduce the risks of IHD and stroke events by 61% (95% CI: 51–71) and 17% (95% CI: 9%–25%), respectively. When considering the reduction of LDL by 0.13 mmol/L, the risk of IHD events

TABLE 2 Changes in energy intake and body weight (with 95% CI) at the end of each year of the fat reduction strategy

Cumulative fat reductions in the food products included	Mean changes in energy intake, kcal/day (95% CI), $n = 2371$	Mean changes in bodyweight, kg (95% CI), n = 1348
1st year (↓4.4%)	− 14.7 (−14.4 to −15.0)	− 0.58 (−0.56 to −0.59)
2nd year (↓8.5%)	− 28.8 (−28.2 to −29.4)	− 1.13 (−1.1 to −1.17)
3rd year (↓12.5%)	− 42.3 (−41.4 to −43.1)	− 1.67 (−1.62 to −1.72)
4th year (↓16.4%)	− 55.2 (−54.1 to −56.2)	− 2.18 (−2.11 to −2.25)
5th year (↓20%)	− 67.6 (−66.1 to −68.8)	− 2.67 (−2.59 to −2.76)

TABLE 3 Mean changes in daily energy intake (95% CI) at the end of the fifth year, by age group

Age group	Number of individuals	Mean kcal reduction (95% CI)
<5	405	− 47.9 (−45.8 to −50.8)
6–10	417	− 73.9 (−71.1 to −76.6)
11–18	484	− 85.1 (−81.6 to −88.7)
19–25	120	− 75.9 (−69.1 to −82.9)
26–35	230	− 76.6 (−71.0 to −82.3)
36–65	751	− 64.9 (−62.4 to −67.7)
66–75	162	− 54.9 (−49.9 to −60.0)
75+	154	− 53.0 (−48.5 to −57.6)

would be reduced by 6.6% (95% CI: 6.2%–8.5%), while the risk of stroke would be reduced by 1.3% (95% CI: 0.6%–2.0%). When applying the 6.6% risk reduction to the 66,341 IHD deaths occurring every year in the United Kingdom, we estimated that our strategy would prevent 4378 IHD deaths (95% CI: 4113–5638) per year. For strokes, when we applied the 1.3% risk reduction to the 36,628 stroke deaths occurring every year in the United Kingdom, we estimated that our strategy would prevent 476 stroke deaths (95% CI: 220–733) per year. If our strategy were to be implemented, 87,560 (95% CI: 82,260–112,760) IHD deaths and 9520 (95% CI: 4400–14,660) stroke deaths would be prevented over 20 years.

Discussion

Evidence shows that changes in the food environment have been fueling the current global obesity epidemic (3). Although energy-dense foods are heavily promoted and widely available, contributing to excessive energy intake and thereby obesity, a limited number of policies have been designed to prompt manufacturers and restaurants to reduce food energy density. Among those are the energy density taxes implemented in Mexico and Hungary, the Chilean Law of Food Labeling and Advertising (i.e., known for the black warning labels), and the mandatory calorie labeling in restaurants in Canada and the United States (31–34). Our results show that, in the UK, a 20% reduction in fat content in all manufactured and out-of-home foods could reduce the prevalences of overweight and obesity by 1.5% and 5.3%, respectively, and prevent 171,840–211,200 incident cases of type 2 diabetes over 20 years. Our proposed strategy aims to reduce energy density through a gradual fat reduction—mainly of SFA—resulting in a reduction of the average LDL cholesterol by 0.13 mmol/L, which in turn would prevent approximately 87,560 IHD and 9520 stroke deaths over 20 years.

The study has several strengths. Our model operates a percentage fat reduction in all the food categories included, so that the biggest fat reduction would occur in those foods that are higher in fat. For example, the maximum fat reduction per 100 g was 6.5 g of fat in foods with high energy density, such as chocolate confectionery. In contrast, the reduction in foods with lower energy density, such as breakfast cereals, was only 0.2 g. When considering a regular portion size, the fat reduction would be very small: around 3 g of fat for a wafer-style chocolate bar and <0.1 g of fat for a portion of breakfast cereal. Our results also show that the average reduction in daily fat intake per person would be only 7.5 g. Evidence shows that meal volume is a more important determinant of satiety than fat content; therefore, it is unlikely that a modest fat reduction would impact satiety negatively (35). Conversely, for most food categories included, a more ambitious fat reduction could be possible, producing further benefits on the population health. Our previous survey on cakes and cookies showed that within each category (e.g., chocolate cake), fat content variation was >30%, thus demonstrating that reformulation by gradually reducing fat content is feasible for the food industry and acceptable for consumers (9). Further evidence supporting the feasibility of our proposed reformulation strategy comes from the United Kingdom's successful salt reduction program. By setting incrementally lower salt targets for over 85 food categories, salt content has been reduced by 20–50% in many food products over 8–10 years (36), resulting in a significant reduction in population salt intake, which led to a decrease in population blood pressure and cardiovascular mortality (37). Many countries have followed the United Kingdom's example and implemented their own national salt reduction programs (36). Similarly, the proposed fat reformulation strategy could also be scaled up to other countries, particularly those in which manufactured and out-of-home food consumption is very high. For manufacturers, voluntary reformulation would be a convenient long-term strategy to avoid the effects of harder policies, such as taxation, front-of-pack nutrition labeling, or warning labels, which are increasingly being implemented worldwide (31–33). In Chile, for example, in response to the implementation of the warning labels, manufacturers have significantly reduced the amounts of unhealthy nutrients in their food and beverages (34).

Second, our model considers the frequency of consumption at the individual level. Therefore, those who frequently consume or consume large quantities of the selected food categories would gain the most benefit in terms of calorie and body weight reductions. We did separate analyses to test the robustness of our main results, and we found that our main findings are conservative. Although we have not been able to model body weight reductions in children and adolescents, our analysis shows that adolescents would be the age group in which the strategy would result in the biggest calorie reduction as compared to the other age groups, since they consume more energy from the selected food categories. Tackling childhood obesity is a priority for the UK government and many other countries, and we recommend our strategy be implemented immediately (38). Interestingly, our analysis shows that people from different income groups would have similar calorie and body weight reductions, thus demonstrating that our strategy would benefit the entire population.

Third, if the UK government implemented our proposed strategy, the population's SFA intake would be lowered to around 10%E, which is the population target recommended by SACN (10). Our strategy focuses on SFA, as this would not only reduce the prevalence of obesity and overweight but also reduce IHD and stroke risks via a reduction in LDL cholesterol (27). Our estimations on IHD and stroke risk reduction are likely to be conservative, as Law and colleagues (27) obtained their risk reduction estimates from short-term clinical trials. The authors speculated that a more substantial risk reduction could occur over a more extended period. Our strategy could result in even greater

FIGURE 3 Mean reduction in SFA (g) and other fat (g) for 100 g of the product category included in the strategy.

health benefits if the fat reduced were to be replaced with high-fiber ingredients, as the average fiber intake would be increased to be closer to the population target of 30 g/day, as recommended by SACN (12, 16).

Our study has several potential limitations. To simplify our calculations, we assumed that underreporting was the same for all the individuals (i.e., 27%). Evidence shows that people with different sociodemographic characteristics, such as age, sex, and educational level, underreport food intake differently (e.g., underreporting is higher in young women than older men). Moreover, underreporting occurs more markedly in obese and overweight individuals and for foods higher in fat and sugar (14, 15). Although we tried to take into account these factors, most probably our adjustment for underreporting is conservative, thus underestimating the effect of the proposed strategy.

Second, we used data from several sources and built models based on previous studies, making the quality of our study dependent on the quality of the data and models used. We used weight loss equations developed and validated by Hall and Jordan (23). The equations have been widely used in several studies, including the Public Health England weight management economic assessment tool (39). We could only predict weight changes for adults because the Hall and Jordan (23) model is not suitable for children, for whom food calories are used for the deposition of new tissues (i.e., growth).

Our study also relied on the quality of the NDNS RP data, which are nationally representative and widely used in public health nutrition research (12). For the LDL reduction, we used the regression equation from the meta-analysis by Yu-Poth and colleagues (26), because this had the advantage of considering the effect of total fat reduction (principally SFA) rather than replacing a type of fat with another. The latter approach (replacing SFA with polyunsaturated fat) has a slightly bigger effect in reducing LDL cholesterol (40, 41) but has a limited impact on reducing overall calories, which is the key goal of our strategy. The equations of Yu-Poth and colleagues (26) are based on 37 dietary intervention trials, mostly in free-living individuals enrolled in the US National Cholesterol Education Programme. This has the advantage of providing an estimate that is likely to reflect real-world, voluntary changes in dietary intake, but may underestimate the effect of our strategy, which focuses on changing the nutritional compositions of manufactured and out-of-home foods.

Another limitation is that we could not account for the effect of age when calculating the reductions in IHD and stroke deaths per year. The published estimates in the study by Law et al. (27) gave relative risks across a limited age range. It was therefore not possible to accurately allow for the effect of age in the model, which was based on the relative risk reduction at age 60. Our estimates are therefore uncertain. Nevertheless, when we applied the relative risk reductions across all ages for which age-based relative risk estimates are known, we obtained results that were similar to the age-unadjusted estimate. Thus, whilst the estimate is uncertain, the error is likely to be modest.

In this study, we modeled a 4% fat reduction to achieve a 20% reduction in 5 years; however, manufacturers could decide to achieve the 20% target all at once. We chose the 20% fat reduction target because evidence shows that this can be easily implemented (9, 42); however, there is no reason why further reductions in fat content could not be made in several energy-dense product categories. We recommend that manufacturers should lower energy density by reducing fat and by replacing this with health-promoting ingredients such as vegetables, fruit, pulses, or whole grain, which are high in dietary fiber and water and are low in energy. By following this approach, the net reduction of calories for each gram of fat reduced would be lower than 9 kcal/g, thus slightly overestimating the energy intake reduction at the individual level. We could not account for these factors in our calculations because the type of ingredient substituted for fat would be different for each food category. For example, a weight-by-weight substitution with vegetables or fruit [which have an average energy density between 0.3–0.9 kcal/g (43, 44)] would result in a reduction of 8.7–8.1 kcal per gram of fat reduced. In the case of substitution with cooked beans and legumes (energy density = 1.3 kcal/g), the net reduction would be 7.7 kcal per each gram of fat reduced (43). Some case studies show that the addition of beans, vegetables, or fruit to reduce energy density can be easily implemented in chilled and frozen categories, such as in pizzas, pasta dishes, meat alternatives, and some ready meals (45). In the processed meat or dairy categories, the physical removal of fat (e.g., trimming fat off meat or using skimmed dairy products) would increase the protein component and reduce the product energy density. In addition, there are several category-specific technologies for the production of reduced-fat products (42). The use of oil cellulose, for example, can reduce the final fat content by 49% in cakes (46). Air frying allows the production of reduced-fat chips or pastries (21), while emulsion technologies allow the incorporation of water into the fat phase of products such as sauces, desserts, and ice creams (42, 47). Another important step to reduce SFA is to switch to oils and fats that have lower SFA contents. Between 90% and 50% of coconut oil, butter, and palm oil is SFA, which could be replaced with oils high in polyunsaturated fat, although such substitutions will not reduce the energy density of the food products (42).

In recent years, most of the reformulation efforts to reduce energy intake have focused on sugar. In the United Kingdom, sugar reformulation has resulted in meaningful energy density reductions in sugar-sweetened beverages due to the implementation of the Soft Drinks Industry Levy (48) and because sugar can be easily reduced in drinks without changes in their volumes. In solid sweet categories, sugar reformulation has shown limited success (48). One possible reason may be that reducing energy density through sugar without making changes in the portion size can be challenging, as starch (which often replaces sugar in a recipe) has the same energy density as sugar (around 4 kcal/g). Our study demonstrates that fat reformulation may be a much more effective strategy for reducing food energy density and energy intake.

In conclusion, our study shows that a 20% reduction in fat content in 46 manufactured and out-of-home food categories could reduce energy intake, and thereby overweight and obesity, in the long term. To maximize population health benefits, manufacturers should reduce SFA and replace this with high-fiber ingredients like fruit, vegetables, legumes, and whole grains. Reducing SFA in the selected food categories would bring the SFA intake within the recommended intakes, reduce LDL cholesterol, and improve the population's cardiovascular health. In general, countries need to implement a mix of policies to tackle complex public health nutrition problems, such as obesity and excessive unhealthy nutrient consumption. If implemented, the proposed strategy alone would result in a substantial reduction of the obesity and overweight prevalence, reduce cases of type 2 diabetes, and prevent IHD and stroke deaths. Our strategy could be used in combination with a fat or an energy density levy (in both the retail and the out-of-home sectors), as evidence shows that fiscal policies ensure successful results and greater compliance, and create a level playing field for the industry (31, 32, 49, 50).

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Data Availability

The data described in the manuscript, codebook, and analytic code will be made available upon email request to the corresponding author.

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