

# International approaches to developing healthy eating patterns for national dietary guidelines

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*As part of the revision of the 2007 Eating Well with Canada's Food Guide, a literature scan on statistical modeling approaches used in developing healthy eating patterns for national food guides was conducted. The scan included relevant literature and online searches, primarily since the 2007 Canada's Food Guide was released. Eight countries were identified as utilizing a statistical model or analysis to help inform their healthy eating pattern, defined as the amounts and types of food recommended, with many common characteristics noted. Detail on international modeling approaches is presented, highlighting similarities and differences as well as strengths and challenges.*

## INTRODUCTION

Since 1942, when the then Canadian federal Department of Pensions and Health introduced *Canada's Official Food Rules*, the national food guide has undergone many revisions in both content and presentation in an effort to maintain relevancy and represent current scientific evidence regarding nutritional health. In 2007, *Eating Well with Canada's Food Guide*<sup>1</sup> was released. Its development included a statistical modeling approach to determine a healthy eating pattern. Healthy eating patterns are defined as the “quantities, proportions, variety or combinations of different foods and beverages in diets, and the frequency with which they are habitually consumed.”<sup>2</sup> The approaches used to develop the 2007 *Eating Well with Canada's Food Guide*<sup>1</sup> built on traditional methods of developing food guides and applied the assessment methodology recommended in the US Institute of Medicine's Dietary Reference Intakes reports.<sup>3,4</sup>

Since 2007, many other countries have updated their national dietary guidance documents and, in some instances, have utilized a modeling approach to inform the development of healthy eating patterns.<sup>4–14</sup> A statistical modeling approach provides quantitative and qualitative information pertaining to the recommended healthy eating patterns, including the recommended number of servings of each food group, and information on the quality of food choices within a food group.

This review was conducted in preparation for the revision of the 2007 *Eating Well with Canada's Food Guide*.<sup>1</sup> The objective was to perform a literature scan and to document the different statistical approaches used internationally to develop healthy eating patterns.

## METHODS

In consultation with nutrition colleagues working on the revision to *Eating Well with Canada's Food Guide*,<sup>1</sup>

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a list of nutritional topics was created for an initial search of published literature using the database Scopus (Figure 1). The database search yielded 1350 journal articles for consideration. After duplicates were removed, the remaining articles were included for full-text review if they met the 3 following criteria: (1) written in English or French; (2) reported on statistical or mathematical modeling methods; and (3) examined national dietary guidance using national nutrition survey data rather than a specific disease or local population (eg, a study using cluster analysis to assess the risk of cancer was excluded, as were studies analyzing adherence to and awareness of food guides).

In addition, since many countries were undergoing revision of national dietary guidelines at the time of the literature scan, an online search was performed that considered the Food and Agricultural Organization of the United Nations (FAO) website for food-based dietary guidelines,<sup>15</sup> along with country-specific websites, to locate documentation pertaining to current practices in the modeling of healthy eating patterns. Using the criteria listed in the previous paragraph, an additional 33 records were identified and included in the literature scan. After full-text review of the remaining 142 articles using criteria (2) and (3) above, 68 articles were retained. Emphasis was then placed on papers published since 2007, when the last *Eating Well with Canada's Food Guide*<sup>1</sup> was developed, so that a total of 49 publications were included in this review.

Furthermore, to obtain published feedback on the various modeling approaches used to develop healthy eating patterns, a citation search of key methodology papers<sup>4-14</sup> was conducted for each country. The database search took place from October to December 2015, while the online and citation searches were conducted from January to July 2016.

## RESULTS

In general, the literature scan revealed 2 different approaches to develop healthy eating patterns: food pattern modeling and dietary pattern analysis. More specifically, the following countries used either food pattern modeling or dietary pattern analysis (or both) in the development of national dietary guidance: Canada, the United States, Australia, the United Kingdom, Brazil, Japan, Denmark, and Ireland. While other countries such as Sweden have recently revised their dietary guidelines, there was no indication that a formal modeling approach was used to determine the recommended healthy eating pattern. Published research originating in other countries (eg, France, the Netherlands) utilized statistical methods such as linear programming to assess particular

aspects of dietary guidance<sup>16,17</sup>; however, the literature scan did not provide information on the use of these methods in national dietary guidance development.

Since the majority of the 8 countries utilized food pattern modeling, the focus of this review is to compare and contrast the approaches to food pattern modeling in the development of healthy eating patterns for national dietary guidance. The use of dietary pattern analysis to inform healthy eating patterns is also discussed. A definition of both approaches is provided below, with further attributes listed in Table 1.

*Food pattern modeling* is defined as the process of developing daily or weekly amounts of foods from different food groups to meet specific criteria (eg, meeting nutrient intake goals, limiting nutrients/foods, varying the proportions or amounts of specific food categories or groups).<sup>2</sup> More specifically, food pattern modeling represents the traditional approach to the development of healthy eating patterns for national food guides, whereby optimal diets are created de novo. This most often involves developing food composites to represent a “typical” serving of a given food group and to help quantify the nutritional content that can be expected from 1 serving of this food group. The number of servings from the various food groups is determined by iteratively adjusting amounts to meet established goals with respect to nutrient adequacy and lower risk of chronic disease. The outputs from food pattern models describe the number of servings and the types of food within each food group or food subgroup that are recommended to meet nutritional goals. Separate food patterns may be established for various caloric levels, age/sex groups, and/or physical activity levels.

*Dietary pattern analysis* identifies and characterizes different dietary patterns in a population. It considers diet information, with or without a specific health outcome, as one of many variables in an analysis of nutrition surveys. Dietary pattern analysis often identifies healthy eating patterns that are associated with different health indicators in a population. Since the relationship between diet and health is multidimensional, advanced statistical procedures may be used to analyze relationships between diet and chronic disease by considering correlations and/or interactions between foods consumed together as part of an individual's diet. Furthermore, additional risk factors, such as smoking status, age, sex, location of eating, income, etc, may be incorporated into these analyses to evaluate other variables associated with the health outcome of interest. Examples of dietary patterns derived in this way include the Dietary Approach to Stop Hypertension (DASH) diet, the Mediterranean-style diet, the vegetarian-style diet, and the Western or traditional diet. Interest in the

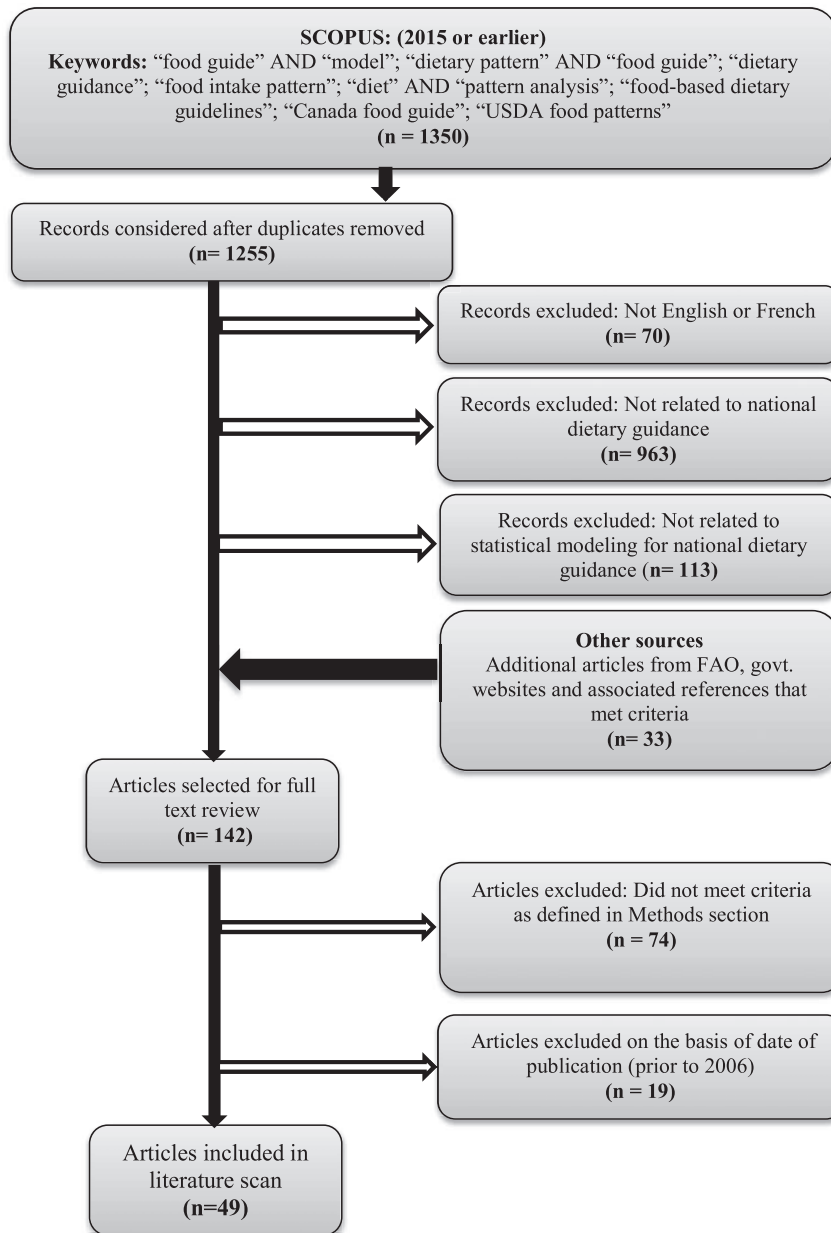


Figure 1 **Flow diagram of the literature search process.** Abbreviation: FAO, Food and Agriculture Organization of the United Nations.

use of dietary pattern analysis to inform the development of national food guides has been growing, and, in 2015, the US Dietary Guidelines Advisory Committee included for the first time a chapter focusing solely on the relationship between dietary patterns and health outcomes.<sup>2</sup>

### MAIN STEPS IN THE FOOD PATTERN MODELING APPROACH

Food pattern modeling has been the traditional method of determining recommended healthy eating patterns and has been adopted by many countries. The results of

the literature search showed that the food pattern modeling approach can be divided into the following 8 distinct steps, although not all steps were used by all countries: (1) Classify foods into food groups and sub-groups; (2) Choose important parameters on which healthy eating patterns are based; (3) Decide how discretionary calories will be treated, if not considered previously; (4) Select nutrient- and/or food-based targets to assess healthy eating patterns; (5) Develop food composites on the basis of food groupings, using national nutrition survey data and nutrient value databases; (6) Using an iterative method, identify the number of servings of each food group or subgroup that meets

**Table 1 Comparison of food pattern modeling and dietary pattern analysis for use in developing healthy eating patterns for national dietary guidance**

Criteria	Food pattern modeling	Dietary pattern analysis
Result	Produces a healthy eating pattern comprising combinations of foods that meet specific nutritional criteria	Defines healthy eating pattern associated with different health indicators in a population
Important variables of interest	Nutrients of interest, food groups, age, sex, physical activity	Foods of interest, other demographic variables or risk factors, health outcomes
Nutrient adequacy	Directly addressed Nutrient adequacy assessed during development of model	Indirectly addressed
Chronic disease outcomes	Indirectly addressed Food subgroups and minimum number of servings established on the basis of health literature Diet often tries to address multiple food/health relationships simultaneously	Directly or indirectly addressed Dietary pattern based on association with (1) specific disease outcomes or combinations of foods consumed together or (2) foods to be avoided or excluded Dietary pattern may differ, depending on the health outcome
Procedure	Iterative process using food composites to determine combinations of amounts and types of food that will meet nutrient targets for various age/sex/physical activity levels Linear or quadratic programming may be used	Statistical modeling techniques used to analyze nutrition survey data, clinical trials data, or a priori studies to determine combinations of foods that are consumed together and/or are associated with health outcomes Statistical methods such as regression analysis, cluster analysis, principal component analysis, CART, etc, are used
Examples	Canada's Food Guide pattern USDA healthy US-style pattern	Mediterranean-style diet, vegetarian diet, DASH diet Western diet, traditional diet
Links/overlap	Dietary patterns associated with specific health outcomes could be tested for nutrient adequacy and acceptability using the food pattern model or, if necessary, an adapted version of the food pattern model	Food pattern generated de novo can be tested for consistency with characteristics of many dietary patterns associated with positive health outcomes

*Abbreviations:* CART, classification and regression tree; DASH, Dietary Approach to Stop Hypertension; USDA, US Department of Agriculture.

nutritional goals and the desired energy level; (7) Assess the adequacy of the healthy eating patterns in comparison with the selected targets; (8) Simulate diets using individual foods and assess the distribution of nutrients of interest.

Steps 1 through 5 represent primarily nutritional decisions; steps 6 and 7 involve statistical/mathematical considerations; and step 8 represents the validation/verification of certain aspects of the previously identified pattern. Many similarities were found in how these 8 steps were applied in the countries studied, but important differences were noted as well, as outlined below.

### 1. Classify foods into food groups and subgroups

As Table 2<sup>9,11,12,18</sup> suggests, most countries classified foods into 4 or 5 general food groups, along with many food subgroups. In most cases, discretionary foods and oils and fats were classified in a separate category. Discretionary foods or calories are defined as the amount of food or calories left over after one's nutrient

needs are met. In many cases, but not all, this refers to foods higher in fat, sodium, and sugars.<sup>2</sup>

While many similarities were noted, 2 main differences were found in the food groupings of Brazil and Japan. For Brazil, foods were placed into 3 groups according to the level of food processing: (1) natural or minimally processed foods; (2) processed foods; and (3) ultraprocessed foods. The Brazilian groupings, based on the NOVA classification, placed discretionary foods separately within the category of processed foods.<sup>19</sup> Other applications of this classification have been considered in the nutrition literature.<sup>20-27</sup>

In Japan, foods were classified into categories of traditional dishes, as opposed to food groups, with the main ingredient of each dish used to classify foods into each category. Dishes that contain several food items as the main ingredients were placed into more than one dish category. The dish-based approach was designed to be an initial step toward a healthy diet for the Japanese population, particularly since it is less quantitative and easier to comprehend by individuals who are less health conscious.<sup>10</sup>

Table 2 Comparison of food group classifications for modeling of healthy eating patterns

Canada (2007)	United States	Australia	United Kingdom	Japan	Denmark	Ireland	Brazil <sup>a</sup>
<b>Vegetables and fruit</b> Fruit and juices Dark green vegetables Orange vegetables Lower-fat potato choices Other vegetables	<b>Dairy</b> <b>Fruits</b> <b>Vegetables</b> Dark green Red/orange vegetables Starchy vegetables	<b>Whole-grain or higher-fiber cereals/grains</b> <b>Refined or lower-fiber cereals/grains</b> <b>Fruits</b> (juice and dried fruit excluded for modeling)	<b>Fruit and vegetables</b> <b>Potatoes, bread, rice, pasta, and other starchy carbohydrates</b> <b>Beans, pulses, fish, eggs, meat, and other proteins</b> <b>Dairy and alternatives</b> <b>Foods high in fat and sugar</b> (oils and fats included within this group) Overall, 125 food subgroups were considered for analysis, organized within the 5 <i>Eatwell Guide</i> <sup>18</sup> food groups	<b>Grain dishes</b> <b>Vegetable dishes</b> <b>Fish and meat dishes</b> <b>Milk</b> <b>Fruits</b>	<b>Fruits and vegetables</b> <b>Fish</b> <b>Breads and cereals</b> <b>Potatoes/pasta/rice</b> <b>Beverages</b> <b>Fats<sup>f</sup></b> <b>Meat and meat products<sup>f</sup></b> <b>Milk and milk products<sup>f</sup></b> <b>Cheese<sup>f</sup></b> <b>Eggs<sup>f</sup></b> <b>Discretionary energy/foods<sup>f</sup></b>	<b>Bread, cereal, and potato group</b> <b>Fruit and vegetable group</b> <b>Milk, cheese, and yogurt group</b> <b>Meat, fish, and alternatives</b> <b>Fats and oils</b> (including fat spreads and oils) <b>Other foods</b> (includes biscuits, cakes, chocolate, confectionary, and savory snacks)	<b>Natural and minimally processed foods</b> (including culinary preparations) Rice Beans Beef or pork Fruits (including juices squeezed from fruit) Other cereals Milk Poultry Roots and tubers Coffee and tea Fish Vegetables Eggs Other naturally or minimally processed foods (eg, nuts and seeds, plain yogurt, peas, soy, seafood) <b>Processed foods</b> French bread Cheeses Processed meat Canned fruits and vegetables <b>Ultra-processed foods</b> Cakes, pies, and cookies Fast food dishes (burgers, hotdogs, and fried and baked snacks) Sugar-sweetened beverages, etc Confectionary Crackers and chips Sausages Ready or semi-ready meals (eg, pizzas, frozen pasta, etc) Sweetened dairy drinks Other ultra-processed foods (margarine, processed sauces and breakfast cereals)
<b>Grain products</b> Lower-fat whole grains Lower-fat non-whole grains	<b>Other</b> vegetables Legumes Other vegetables	<b>Green and brassica vegetables</b> <b>Orange vegetables</b> <b>Starchy vegetables</b> <b>Other vegetables</b> <b>Legumes</b> <b>Nuts and seeds</b> <b>Red meats</b> (Beef, veal, lamb, pork, kangaroo)					
<b>Milk and alternatives</b> Lower-fat fluid milk and fortified plant-based beverages Other lower-fat milk products	<b>Grains</b> Whole Refined <b>Protein foods</b> Meats Poultry Seafood (high n-3) Seafood (low n-3) Eggs Nuts/seeds Processed soy products	<b>Green and brassica vegetables</b> <b>Orange vegetables</b> <b>Starchy vegetables</b> <b>Other vegetables</b> <b>Legumes</b> <b>Nuts and seeds</b> <b>Red meats</b> (Poultry, fish, seafood, eggs, legumes) <b>Higher-fat dairy foods<sup>c</sup></b> <b>Medium-fat dairy foods<sup>c</sup></b> <b>Lower-fat dairy foods<sup>c</sup></b> <b>Unsaturated oils and spreads<sup>d</sup></b> <b>Discretionary choices<sup>e</sup></b>					
<b>Meat and alternatives</b> Lower-fat fresh meat Fresh and processed fish and shellfish Eggs Pulses/alternatives	<b>Oils</b> <b>Solid fats<sup>b</sup></b> <b>Added sugars<sup>b</sup></b>						
<b>Foods outside the 4 food groups</b> Unsaturated fats (margarine, oils) Other/miscellaneous foods (condiments, spices)							

<sup>a</sup>Food groups as analyzed in da Costa Louzada et al.<sup>1,12</sup>

<sup>b</sup>These 2 food groups form part of the discretionary calories, whereas amounts from other food groups are defined as essential calories.

<sup>c</sup>Subgroups of foods combined in final model.

<sup>d</sup>Food groups not weighted for current consumption levels within each age/sex group.

<sup>e</sup>Group only included in modeling of total diets.

<sup>f</sup>Not included in the 2005 Danish dietary guidelines.<sup>9</sup>

## 2. Choose important parameters on which healthy eating patterns are based

Six countries considered age and sex to be important parameters and thus developed separate patterns based on these parameters. For Canada, the United States, Australia, Ireland, and Japan, the age/sex groups were similar to those used for the US Institute of Medicine's Dietary Reference Intakes, ie, 2–4 years (sexes combined), 4–8 years (sexes combined), and, with separate groups for males and females, the age groups 9–13 years, 14–18 years, 19–30 years, 31–50 years, 51–70 years, and 71 years and older. Australia also modeled patterns for pregnant and lactating females in various age groups (14–18 years, 19–30 years, and 31–50 years). The United Kingdom developed only one pattern for all individuals over 18 years of age and for one caloric intake (1711 kcal), which represented the average current energy intake based on the most recent national nutrition survey data. The Denmark model developed a single, combined-sex group for adolescents aged 11–15 years.

Energy needs differ by age, sex, and level of physical activity, and therefore the level of physical activity was also considered an important parameter in the development of a healthy eating pattern. The US *Dietary Guidelines for Americans 2015–2020*<sup>28</sup> established 12 energy levels, ranging from 1000 to 3200 kcal, using estimated energy requirements for various age/sex groups and physical activity levels. Japan established 3 energy levels and then adjusted the number of portions in each dish category to allow a range of 1600 to 2800 kcal to be considered for males and females of different ages. Denmark established an initial energy level of 2300 kcal (moderate physical activity level) and later adjusted the energy level to 2 energy levels, 1690 kcal (light physical activity) and 3290 kcal (heavy physical activity), to ensure the pattern was applicable to the target population of all adolescents. Ireland developed eating patterns that provide a range of calories for sedentary individuals (except children aged 5–13 years) and moderately physically active individuals for the various age/sex groups. Different daily calorie requirements in increments of 200 calories aimed to ensure food patterns for both sexes comprehensively covered the range of differing energy requirements for the healthy population aged 5 years and older.

Australia developed an initial “foundation diet” for the least-active individuals who were the smallest (in adult groups) and youngest (in child groups), which represented the minimum food intake to meet nutrient adequacy. A total diet was then derived, which extended these values to still meet nutrient adequacy but allowed for additional caloric intake for people of other body

sizes and higher levels of physical activity. The total diets were established in a stepwise manner, such that additional calories were added to the foundation diets and then the number of servings was adjusted accordingly.

The United Kingdom developed only one food pattern (providing 1711 kcal) for all individuals over 18 years of age. This caloric value represented the weighted average energy intake for all adults over 18 years of age from the UK *National Diet and Nutrition Survey*<sup>29</sup> for the years 2008 to 2011. Energy was included in the modeling as one of the macronutrient constraints, in the sense that the optimized diet would not result in an increase in kilocalories from current diets. The Canadian model in 2007 used only a sedentary level of physical activity to develop healthy eating patterns, and individuals with other physical activity levels were recommended to choose extra food from the 4 food groups of the recommended healthy eating pattern.

## 3. Decide how discretionary calories will be treated

Three countries (Canada, Japan, and Ireland) did not include discretionary calories in the final models. Canada considered a food pattern model for a sedentary physical activity level only; however, a discretionary-type food subgroup that allowed for the addition of condiments was included in the pattern. Two countries (United States and Denmark) used the modeling procedure to determine the number of servings for each food group or subgroup that met nutritional goals, doing so for each energy level considered in step 2. Then, the number of calories assigned to each food group or subgroup (United States) or food group (Denmark), along with the calories assigned to oils, was summed and considered essential calories. A limit for discretionary calories (solid fats and added sugars) was calculated by subtracting essential calories from the caloric goal for the pattern.

The United Kingdom included a category of “Foods high in fat and sugar” as part of their model development. This category included sugar-sweetened beverages, low-calorie beverages, cakes, etc, along with oils and spreads as a separate food subcategory. The model outputted the average daily consumption (48 g/d), which was converted into a proportion of daily consumption (3.8%) for this group within Public Health England's *Eatwell Guide*.<sup>18</sup>

Australia's modeling provided the most in-depth assessment of discretionary calories, as it conducted additional modeling to build a total diet for individuals with various body sizes and higher levels of physical activity. These total diets expanded upon foundation diets,

first permitting more choices from vegetable, fruit, cereals, and nut and seed groups to reach the higher energy allowances. Options were also provided to select some discretionary choices of foods and beverages with higher fat/sugar/alcohol content and lower overall nutrient density. Total diets resulted from relaxing the constraints on the number of servings in the foundation diet models. No limits, other than overall energy targets, were set on these food groups in the modeling process. Additional servings could come from the dairy, red meat, and poultry/fish/seafood/eggs/legumes group or from “discretionary choices,” as long as targets were met for overall energy and macronutrient composition of the diet models.<sup>7</sup>

Once the samples of Australian total diets were initially developed using the composites in each food group, they were tested by simulating 100 seven-day diets. A variety of total diets were built to reach the following 2 levels of energy need: (1) average energy needs within each age/sex group (for adults of mid body size or children in the mid age group, both with a physical activity level of 1.7, which represents light to moderate physical activity); and (2) highest energy needs within each age/sex group (for tallest adults or children in oldest age group, both with a physical activity level of 2.0, which represents heavy occupational or high leisure activity).

#### **4. Select nutrient- and food-based targets to assess healthy eating patterns**

Table 3 describes the various nutrients that were considered in the modeling for the countries that developed a food pattern model. In most cases, similar micro- and macronutrients were considered. Further detail on how the nutrient adequacy was assessed for each model is provided in step 7.

Some countries chose to include food-based targets (often termed *acceptability constraints*<sup>16,22</sup>) for their healthy eating patterns. Australia set minimum and/or maximum limits for specific foods on the basis of evidence of the health effects of these foods. Other factors such as variety, cultural acceptability, accessibility, and availability within the Australian food supply were also considered when setting limits.<sup>7</sup> Similarly, the United Kingdom set food-based targets so that the pattern would satisfy UK dietary recommendations for fruits and vegetables, fish, and red and processed meat.

#### **5. Develop food composites on the basis of food groupings, using national nutrition survey data and nutrient value databases**

Five countries (Canada, United States, Australia, Japan, and Denmark) developed food composites using

national nutrition survey data to assist in determining the quantity and quality of foods for which guidance is provided through the healthy eating pattern. The exceptions were Ireland and the United Kingdom. Although high-quality nationally representative dietary survey data for Ireland were available, Ireland’s Steering Committee on Revision of the Healthy Eating Guidelines deemed the use of that data and a modeling approach that involves food composites beyond the resources available.<sup>30</sup> Instead, a so-called practical approach was used, whereby input from experienced dietitians and nutritionists familiar with eating habits in Ireland was used to develop 22 sets of 4-day food patterns for theoretical individuals chosen from different age/sex groups. Instead of creating food composites, the United Kingdom used all foods reported in the *National Diet and Nutrition Survey*,<sup>29</sup> along with their nutrient profiles for 125 food subgroups, to calculate mean consumption (grams per day) and mean nutritional quality (grams of macro- and micronutrients per 100 g of diet) for macronutrients and micronutrients.<sup>8</sup>

In general, food composites developed using national survey data were seen as an important feature of the modeling process, as they incorporate aspects of food availability, accessibility, and affordability for a wide variety of individuals into the model.<sup>7</sup> Food composites were created to obtain a representative nutrient profile for 1 serving of each food subgroup used in the modeling approach and were generally derived on the basis of 2 factors: popularity (amounts consumed) of foods in modeling food groups or subgroups, and nutrient content of representative foods.

The popularity of a food is used to provide a relative “weight” of each individual food within the composite and represents the likelihood of each food being consumed. All 5 countries mentioned above used national survey data to calculate the popularity of each food.

Nutrient content of representative foods within each food group or subgroup was used to calculate the nutrient profiles of food composites. The choice of representative foods varied between the countries considered.

While popularity of foods was based on the most recent food consumption data available for all countries, differences were noted in how the nutrient profile of a food composite was calculated. In Japan, all foods within the food grouping were included in the calculation of both the popularity and the nutrient profiles of the food composite. For Canada, all foods within the lower-fat subgroups were included in both calculations. In the United States, all foods were included to calculate popularity, but only one representative (nutrient-dense)

**Table 3 Comparison of energy and nutrients considered in dietary pattern modeling**

Nutrient category	Nutrient	Canada	United States	Australia <sup>a,b</sup>	United Kingdom <sup>a,b</sup>	Japan	Denmark	Ireland	Brazil
Energy	Energy	X	X	X*	X*			X	X
Nutrients with an AMDR	Energy density								X
	Carbohydrate	X	X	X+	X*	X	X		X
Nutrients without a DRI recommendation	Fat	X	X	X+	X*	X	X	X	X
	Protein	X	X	X*	X*	X	X		X
	Saturated fat	X	X	X+	X*		X	X	X
	Dietary cholesterol	X	X	X+		X			
	Sugar			X+				X	
	Free sugar				X*				X
	Added sugar							X	
	EPA		X						
	DHA		X						
	PUFAs	X	X	X+				X	
Nutrients with an EAR	MUFAs	X	X	X+			X		
	Cis/LC n-3 fatty acids			X+	X+				
	Starches			X+					
	Folate	X	X	X*	X+		X		
	Magnesium	X	X	X*			X		X
	Niacin	X	X	X+			X		X
	Phosphorus	X	X	X+			X		X
	Riboflavin	X	X	X+	X+	X	X		X
	Thiamin	X	X	X*	X+	X	X		X
	Vitamin A	X	X	X*	X+	X	X		X
Nutrients with an AI	Vitamin B <sub>6</sub>	X	X	X+	X+		X		X
	Vitamin B <sub>12</sub>	X	X	X+	X+		X		X
	Vitamin C	X	X	X*	X+	X	X		X
	Zinc	X	X	X*	X+		X		X
	Iron	X	X	X*	X+	X	X	X	X
	Vitamin E			X+	X+				X
	Calcium	X	X	X*	X+	X	X	X	X
	Vitamin D	X	X	X+	X+		X	X	X
	Selenium		X	X+			X		X
	Copper		X						X
Nutrients with an AI	Iodine			X*	X+				
	Linoleic acid	X	X	X+					
	Alpha-linolenic acid	X	X	X+					
	Potassium	X	X	X+	X+	X	X		X
	Sodium	X	X	X+	X*	X			X
	Fiber	X	X	X+	X*	X	X	X	X
	Vitamin K		X				X		
	Choline		X						
	Manganese		X						X

Abbreviations: AI, Adequate Intake; AMDR, Acceptable Macronutrient Distribution Range; DHA, docosahexaenoic acid; DRI, Dietary Reference Intakes; EAR, Estimated Average Requirement; EPA, eicosapentaenoic acid; LC, long-chain; MUFAs, monounsaturated fatty acids; PUFAs, polyunsaturated fatty acids.

<sup>a</sup>Australia and the United Kingdom also considered food-based targets to develop healthy eating patterns.

<sup>b</sup>For Australia and UK modeling, X\* = constraints or “drivers” used in mathematical optimization, X+ = assessed as an output only.

food in each “item cluster” was included when calculating the nutrient profile. Item clusters consisted of similar foods that were consumed in the same way, ie, raw and cooked foods were placed into different clusters. An item cluster was created if consumption was more than 1% of total servings consumed within each subgroup, according to the most recently available National Health and Nutrition Examination Survey food consumption data.<sup>2</sup> To the extent possible, the representative foods for these item clusters were lean, fat free, or low fat, with no added sugars or sodium. For example, the red-orange vegetable subgroup had 12 item clusters,

including cooked carrots, raw carrots, cooked tomatoes, and raw tomatoes. While cooked carrots may be consumed in many forms, plain cooked carrots were selected as the representative food for this cluster. The US modeling approach noted that there were some instances for which the same representative food was used in different item clusters. As an example, “orange juice, chilled, including from concentrate” was used as the representative nutrient-dense food for the Orange Juice item cluster as well as for the item clusters Mixed Fruit Juice (Citrus) and Unknown Citrus Fruit Juice within the Fruit Juice subgroup.



Australia considered an approach somewhere in between, in that all food categories were included to calculate the popularity of foods, but only nutrient-dense foods were retained within each food category to calculate the nutrient profile. Similarly, Denmark included all foods to calculate popularity but retained only “basic foods with no added sugar and/or fat and low fat content” to calculate nutrient composition.

## **6. Identify the number of servings of food (for each food group or subgroup) that meets nutritional goals and energy level using an iterative method**

All 7 countries, regardless of the use of food composites, used an iterative approach to determine the number of servings within each food group and food subgroup that met nutritional goals. Two main iterative methods were considered: trial-and-error, and mathematical optimization (linear or quadratic programming).

Canada, the United States, Japan, and Denmark used the trial-and-error method, whereby an initial number of servings of each food composite was chosen, which was then increased or decreased to meet nutrient targets for each age/sex group and/or caloric level. Ireland also iterated servings for their theoretical individuals by trial and error to ensure nutrient targets were satisfied.

Australia and the United Kingdom used an optimization procedure to choose the number of servings in composite modeling subject to certain defined dietary constraints (eg, meeting nutrient and food-based targets). Linear programming, which is a form of optimization modeling, is a method to optimize an outcome subject to a set of constraints (ie, minimum and/or maximum values). Linear programming and its extensions have been widely used in economics, business, and operational research applications and have recently been implemented in a variety of nutritional applications.<sup>16,17,31–36</sup>

Australia used linear programming to define diets that met nutrient and food group requirements within minimal deviation of the energy requirements of the smallest least-active individual (foundation diets). The United Kingdom also used optimization modeling to determine the modeled consumption (grams per day) that minimized the squared deviation between current consumption and a more optimized diet that met macro/micronutrient and food-based constraints. In particular, 2 constraint scenarios were modeled: the *Eatwell Guide*<sup>18</sup> scenario, which included all of the new UK dietary recommendations, and the “old” recommendations scenario, which included the older recommendations for free sugars and fiber made prior to the

update provided in the Scientific Advisory Committee on Nutrition (SACN) *Carbohydrates and Health* report.<sup>37</sup>

## **7. Assess adequacy of the healthy eating pattern in comparison to nutrient targets**

All countries evaluated the nutritional adequacy of the given number of servings at each iteration on the basis of targets for nutrients listed in Table 3. If nutrient adequacy was not met, then the number of servings was adjusted and results were rerun and compared with nutrient targets. The goals and procedure for assessing nutrient adequacy varied, depending on whether simulated diets were used (Canada, Australia) or/and whether the number of servings from food composites was considered (Canada, Australia, United States, Japan, and Denmark). In the United Kingdom, when the modeled diet was determined, the amounts of macronutrients and micronutrients were calculated and compared with recommended values. Ireland also evaluated the nutritional adequacy of the diets of their theoretical individuals iteratively, adjusting the pattern until nutrient goals were satisfied.

Table 4<sup>3,8,9,29,30,38,39</sup> provides a summary of the assessment of nutrient adequacy conducted by each country for their modeling approach.

## **8. Simulate diets using individual foods and assess distributions of nutrients of interest**

Only 2 countries (Canada and Australia) undertook this step, in which simulated diets were created on the basis of the food pattern developed using composite modeling. The simulated diets were composed of individual foods, chosen on the basis of their popularity, as opposed to food composites. This was an expansion upon the traditional method of food pattern modeling outlined in steps 1 through 7 above.

In the Canadian model, 500 simulated diets aligned with the healthy eating pattern identified with the trial-and-error approach were randomly generated for each age/sex group. The probability of an individual food being selected in the diets depends on the relative importance of that food within the lower fat modeling subgroups. As an example, if lettuce represented 8% of vegetable portions eaten by women aged 31 to 50 years, then, for the simulated diets for this age group, there was an 8% chance that lettuce would be selected as a serving of vegetables.<sup>4</sup> Simulated diets were then assessed using the Estimated Average Requirement (EAR), Adequate Intake (AI), Tolerable Upper Intake Level (UL) or Acceptable Macronutrient Distribution Range (AMDR), depending on the micro- or macronutrients considered (Table 4). The food pattern was then

Table 4 Comparison of procedures to assess the nutrient adequacy of food pattern models<sup>a</sup>

Canada	United States	Australia	United Kingdom	Japan	Denmark	Ireland
<p><b>Food composites</b> In step 1, a preliminary pattern (no. of servings) for each modeled subgroup was established, with nutrient adequacy defined as meeting 100% of the RDA or AI, depending on the nutrient.</p> <p><b>Simulated diets</b> In step 2, simulated diets were created. For vitamins and minerals with an EAR, &lt; 10% of simulated diets in any DRI age and sex group should have a nutrient content below the EAR. A threshold of 10% was used because the simulated nutrient distributions were not adjusted to estimate the usual nutrient content.</p> <p>For nutrients with an AI, the median nutrient content of simulated diets should approximately equal the AI. For macronutrients, ≥ 80% of simulated diets should have values within the lower and upper bounds of the AMDRs. For nutrients with a UL, no diets should have</p>	<p><b>Food composites</b> The goal of determining a pattern was to have an intake at the RDA or AI level or higher. Iterative changes were made when needed, until 100% of nutritional goals were met or were within a reasonable range of being met (usually at least 90% of the RDA or AI). Amounts in excess of the RDA or AI were considered acceptable as long as they did not exceed the UL for that nutrient.</p> <p>For macronutrients with an AMDR, the goal was to be within the specified range. Nutritional goals for saturated fat (&lt; 10% of calories) and cholesterol (&lt; 300 mg/d) were considered.</p> <p>For sodium, a daily intake of less than the UL of 2300 mg was used.</p> <p>For dietary fiber, the daily goal of ≥ 14 g per 1000 kcal was used.</p> <p>Amounts from all food groups and subgroups were compared within the limits of the 5th and 95th percentiles of the usual intake for</p>	<p><b>Foundation diets</b> <b>Food composites</b> In Stage 1 of the modeling, using linear programming, an optimal dietary pattern was determined if energy was minimized and the 10 defined important nutrients met the RDAs for each age and sex group on the basis of composite food groups.</p> <p>Since the energy provided in Foundation diet models was close to the individual's total energy requirements, the results of these models were also compared against AIs and AMDRs for other macro- and micronutrients to ensure serving sizes were acceptable.</p> <p><b>Simulated diets</b> In Stage 2, a secondary check of the patterns was conducted using simulated diets based on actual individual foods within each age/sex group. The dietary pattern was deemed acceptable if all 100 7-day simulations met the EAR for the 10 nutrients driving the model.</p>	<p><b>Food composites: N/A<sup>b</sup></b> All foods reported in the UK <i>National Diet and Nutrition Survey</i><sup>29</sup> and their nutrient profiles for 125 food subgroups were used to calculate mean consumption (grams/day) and mean nutritional quality (grams per 100 g of diet) for macronutrients and micronutrients. Once the modeled diet was determined, the amounts of macronutrients and micronutrients were calculated and compared with recommended values.</p> <p>Table 2 of Scarborough et al.<sup>8</sup> describes the average intakes in further detail.</p> <p>Detail on the percent daily recommended value and the percent recommended nutrient intake is also provided for specific nutrients.</p> <p><b>Simulated diets</b> No simulated diets were calculated</p>	<p><b>Food composites</b> Little detail was provided, although Murphy and Barr<sup>38</sup> indicated that the Japanese Dietary Reference Intakes were used to assess nutrient targets. Specifically, the RDA or AI was targeted for the nutrients under study.</p> <p><b>Simulated diets</b> No simulated diets were calculated</p>	<p><b>Food composites</b> The micro- and macronutrient compositions of the diets were calculated.</p> <p>In general, the goal of the food intake pattern was to provide the recommended intakes of dietary fiber and macronutrients as percentages of total energy intake (%E) and an intake of 17 vitamins and minerals corresponding to recommended intakes of the <i>Nordic Nutrition Recommendations</i> 2004<sup>39</sup> for children and adolescents aged 11–15 years.</p> <p>Table 2 of Bittoff-Jensen et al.<sup>9</sup> provides detail on the comparison of results from the recommended food intake pattern with the <i>Nordic Nutrition Recommendations</i> 2004<sup>39</sup> values.</p> <p><b>Simulated diets</b> No simulated diets were calculated</p>	<p><b>Food composites/simulated diets: N/A<sup>b</sup></b> Twenty-two sets of 4-day food patterns were developed for theoretical individuals with different caloric needs and were evaluated against nutrient goals for different age and sex groups. Those goals are provided in Table 1, Section 2 of the <i>Scientific Recommendations for Healthy Eating Guidelines in Ireland</i>.<sup>30</sup></p> <p>In general, these goals were based on the <i>Nordic Nutrition Recommendations</i> 2004<sup>39</sup> (EARs), while the goals for calcium and vitamin D are the Als recommended by the US Institute of Medicine<sup>3</sup></p>

(continued)

Table 4 Continued

Canada	United States	Australia	United Kingdom	Japan	Denmark	Ireland
a nutrient content at or above the UL. For saturated fat, $\leq$ 10% of calories and $\leq$ 300 mg of dietary cholesterol were used as benchmarks for median nutrient content	each age and sex group as calculated using the National Cancer Institute method. For under-consumed food groups and dietary components, recommended amounts were compared with the median and 95th percentiles of intakes. For overconsumed food groups and dietary components, recommended amounts were compared with the 5th percentile and median intake levels.	After the 100 seven-day diets were created, the nutrient composition of each of the 7-day diets, as well as the number of diets that were at or above the EAR for each nutrient, was determined.				
	<b>Total diets</b> In Stage 3, total diets were originally developed using the composite foods and were tested using simulated diets, in the same manner as Stage 2 for foundation diets (see step 3 in text: "Decide how discretionary calories will be treated")					
	<b>Simulated diets</b> No simulated diets were calculated					

Abbreviations: AI, Adequate Intake; AMDR, Acceptable Macronutrient Distribution Range; DRI, Dietary Reference Intake; EAR, Estimated Average Requirement; NA, not applicable; RDA, Recommended Dietary Allowance; UL, Tolerable Upper Intake Level.

<sup>a</sup>Brazil was not included since food pattern modeling was not performed.

<sup>b</sup>In the United Kingdom and Ireland, "typical" servings were derived differently than the food composites derived in other countries; thus, the term *Food composites* was not used.

modified iteratively as needed to achieve satisfactory results.

In the Australian model, 100 7-day simulated diets were constructed for each age/sex group. The simulated diets were generated in much the same way as in Canada, with individual foods being entered into diets in proportion to how often they were consumed by a given age/sex group. The dietary pattern was deemed acceptable if all 7-day simulated diets met the EAR for the 10 nutrients driving the model. After composing 100 7-day diets, the program calculated the nutrient composition of each of the 7-day diets and then calculated how many diets were at or above the EAR for each nutrient. If a high percentage of 7-day diets did not meet the EARs, the food patterns were modified in an iterative fashion to determine if there were alternative choices that could be made to allow all simulated diets to meet the EARs.<sup>7</sup>

### DIETARY PATTERN ANALYSIS AND THE DEVELOPMENT OF NATIONAL FOOD GUIDES

The literature scan noted that nutrient-based approaches to modeling, such as the food pattern models presented previously, have been recently criticized since they do not directly account for the relationships between diet and the risk of chronic diseases. Authors have noted that food-based approaches, which rely on dietary pattern analyses, consider the complex and synergistic contributions from diet and other variables, not solely age, sex, and physical activity level.<sup>2,40,41</sup> The use of dietary pattern analysis in developing dietary guidance was highlighted as having numerous strengths,<sup>2,42</sup> particularly since the method considers the relationship between the overall diet and its constituent foods, beverages, and nutrients in relationship to outcomes of interest. Such analysis permits examination of interactions between foods and nutrients in promoting health or increasing disease risk. The dietary pattern analysis approach has advanced nutrition research by capturing overall food consumption behaviors and quality in relation to health.<sup>2,40,41</sup>

Conversely, limitations to the dietary pattern analysis approach have been cited.<sup>2</sup> Particularly, since dietary assessment instruments (such as the food frequency questionnaire and 24-hour recalls) are based on self-reported data, these may introduce report bias that could attenuate diet–health relationships. Second, the term *dietary patterns* is not consistently defined by investigators and may vary from one study to another, which inhibits study reproducibility. In addition, certain statistical approaches used to measure dietary patterns are data driven, meaning they apply to the specific population under study and are difficult to generalize.

Recent revisions to national food guides have attempted to incorporate evidence on dietary patterns deemed healthy, such as vegetarian and Mediterranean diets, into national dietary guidelines. In particular, 3 countries have considered results from dietary pattern analysis in recent revisions of their national dietary guidance: the United States, Australia, and Brazil. As examples of such considerations, the United States and Australia considered foods avoided or excluded (eg, vegetarian), while Brazil considered the level of food processing when assessing diet quality.

### APPLICATION OF DIETARY PATTERN ANALYSIS TO RECOMMENDED HEALTHY EATING PATTERNS

#### United States and Australia

Australia and the United States developed additional patterns of eating in addition to a general (omnivore) food pattern model. In particular, the United States modeled 2 additional patterns: a US healthy vegetarian (lacto-ovo) pattern and a US Mediterranean-style pattern.<sup>2</sup> Australia modeled 3 additional patterns: pasta-based, rice-based, and vegetarian (lacto-ovo vegetarian).<sup>7</sup> These additional patterns retained the same structure as the food pattern models for the general (omnivore) diet, but the number of food groups and/or the number of servings was adjusted on the basis of findings from dietary patterns analysis. Similar nutrients were assessed for nutrient adequacy for various caloric levels within the age/sex groups considered previously. Australia also used simulated diets for the 3 additional patterns.

As an example, the US healthy vegetarian eating pattern modeled additional amounts of soy products (tofu), legumes, nuts and seeds, and whole and total grains; while servings of meat, poultry, and seafood were removed. No change was made to servings of fruits and vegetables or dairy, as an analysis noted no significant differences between self-identified vegetarians and nonvegetarians.<sup>43</sup> For the US Mediterranean-style pattern, servings of fruits and seafood were increased, and servings of dairy were decreased. While amounts of red and processed meats are higher in Mediterranean diets compared to the US pattern, no change was made to the number of servings in this category in the US model, since the amounts of saturated fat and sodium are high in American diets. In addition, while whole grains tend to be lower in Mediterranean diets, the assessment noted that little consistency was found in the composition of this category.<sup>2</sup> No changes to the number of servings of whole grains were made.

In Australia, a rice-based diet was modeled that used additional food subgroups of white rice

(1 serving = 120 g) and whole-grain or brown rice to better reflect the diets of citizens of Asian origin. Such diets also included more legumes and less potatoes, cheese, meats, and refined cereals. For pasta-based diets, additional categories of refined pasta and whole-grain pasta were considered, along with additional servings of legumes, nuts and seeds, and green vegetables. In addition, less red meat, more white meats and fish, slightly more cheese, and less-refined cereals and potato were included.

For the Australian lacto-ovo vegetarian pattern, an approach similar to that used to develop the US healthy vegetarian eating pattern was devised, whereby a new food group was created that contained a mix of legumes, eggs, nuts, and seeds to replace the meat component of omnivore diets. This mix was devised to ensure an amino acid balance in a ratio of approximately 5 servings of legumes to 1 egg to 1 serving of nuts and seeds. Since no Australian national data were available regarding choices within food categories for lacto-ovo vegetarians, the same within- food group proportions were used as for the omnivore food group. Increased vegetarian iron and zinc Recommended Dietary Allowances and EARs were used to assess nutrient adequacy. Patterns for lacto-ovo vegetarian and pasta- and rice-based diets were developed using the same approach as for omnivore diets (ie, using both composite modeling and simulated diets).

## Brazil

In 2014, the government of Brazil released the second edition of the *Dietary Guidelines for the Brazilian Population*.<sup>44</sup> The dietary guidelines were based on a statistical analysis undertaken by the Brazilian Institute of Geography and Statistics between May 2008 and May 2009. Characteristics of Brazilian dietary patterns were described using data from the Brazilian Household Budget Survey.<sup>45</sup>

A defining aspect of the Brazilian dietary guidelines was the characterization of foods on the basis of level of food processing. In related technical papers, food processing is defined as “all methods and techniques used by industry to turn whole fresh food into food products.”<sup>46,47</sup> The guidelines classify foods not into conventional food groupings on the basis of origin, use of food, or nutrient composition but rather into 3 categories on the basis of level of food processing, specifically natural or minimally processed foods, including culinary preparations using these food items (Group 1); processed foods (Group 2); and ultraprocessed foods (Group 3).

A statistical analysis of national dietary information was conducted, whereby individuals were classified into

5 strata (quintiles) according to the caloric value that ultraprocessed foods contributed to the total value of their diet. Linear regression analysis was used to describe the trend and the association between the quintiles and micronutrient content of the diet, with and without adjustment for sociodemographic and socioeconomic characteristics.

The statistical analysis showed that the 20% of Brazilians who consumed fewer ultraprocessed foods meet or are close to meeting the nutritional recommendations of the World Health Organization.<sup>11,12</sup> This finding informed the development of the Brazilian Ministry of Health’s guidance to “Make natural or minimally processed foods the basis of your diet.”<sup>44</sup> The Brazilian guidelines deliberately omitted information on the amount of each food to consume and the total calories in each meal.

## DISCUSSION

This literature scan of approaches to modeling healthy eating patterns showed that, while approaches varied from country to country, there were many similarities. Most countries that applied the food pattern model approach used food composites and similar nutrient targets, and some countries used simulated diets to account for the variability resulting from individual food selection. Differences were noted in groupings of foods, consideration of energy, and the method to consider discretionary calories in the modeling.

While food pattern models and dietary pattern analyses originate from different methodologies, both lead to a pattern of healthy eating, and there are links between the 2 methods. In particular, dietary patterns found to be associated with specific health outcomes could be tested for nutrient adequacy and realism using the food pattern model and adapted, if necessary, as revealed by the US and Australian additional patterns. Conversely, a food intake pattern generated through food pattern modeling can be tested for consistency with the characteristics of dietary patterns associated with positive health outcomes.

The development of food composites has been seen as a rigorous and objective approach to establishing food patterns and has the advantage of being realistic and practical, since these composites incorporate consumption information from the particular country and reflect the available food supply.<sup>7,13,14,38,48</sup> Since nutrient profiles reflect relative consumption, limitations of this approach are that some composites may provide relatively low levels of certain nutrients if richer sources are less commonly consumed.<sup>30,49</sup> As an example, the Australian model noted that 53% of the vegetable category was composed of potatoes, which have a low

nutrient density compared with other vegetables. Many countries addressed this challenge by creating more specific subgroups of foods, along with corresponding composites. For example, Australia isolated potatoes and other starchy vegetables into a separate food subgroup.

Another limitation is the possible inclusion of only nutrient-dense forms of foods in composites by some countries. A study of the 2010 US Department of Agriculture food patterns<sup>50,51</sup> found that, despite adhering to the amounts of foods in the patterns, many nutrient goals were not met when typical, as opposed to nutrient-dense, choices were made. Challenges have also been identified in communicating nutrient-dense choices to consumers, given the lack of a quantifiable definition of nutrient density and the ambiguity of this term.<sup>52</sup>

Conversely, the Japanese approach, which was originally developed to simplify information with respect to healthy eating choices, has been criticized for a lack of precision.<sup>10,38</sup> Other food guides recommend a more specific diet than the Japanese guide and thus may result in a better nutrient adequacy among individuals who follow such recommendations.<sup>38</sup>

The use of mathematical optimization to select an optimal number of servings subject to nutritional constraints, as utilized by the Australian and United Kingdom models, was seen as a more objective approach over trial-and-error methods.<sup>7,8</sup> The use of optimization models for Australia and the United Kingdom differed in the choice of objective function and the number of constraints considered. Australia utilized micro- and macronutrient constraints, along with additional food-based constraints, to limit quantities of specific food groups and to ensure optimal diets satisfied cultural needs and contained realistic food quantities.<sup>7</sup> The United Kingdom included macronutrients, fiber and sodium constraints and chose an objective function to minimize deviation from current consumption, which mitigated the need for such acceptability constraints. However, the model results yielded a decrease in zinc in the optimized diet to slightly less than the recommended intake.<sup>8</sup>

The use of simulated diets, as originated by the Canadian food pattern modeling approach and further extended by the Australian approach, was viewed positively, in that simulated diets were evaluated with the goal of ensuring the recommended food patterns would be broadly applicable. The Canadian model was seen as an extension of the approach used in the development of the food guides for the United States and Japan, since simulated diets assess whether individuals who consume the specified amount of food from each of the food groups but whose food choices may deviate

significantly from the popular foods contained in composites can still meet nutritional goals.<sup>38,53</sup>

The Canadian model was criticized for not providing patterns for particular caloric intake and not including a category of discretionary calories in the final food pattern.<sup>41,54–56</sup>

Modeling of multiple healthy eating patterns, as undertaken by Australia and the United States, has been lauded as a way to accommodate cultural preferences of multiethnic groups, supports growing evidence that there is more than one strategy for healthy eating and reiterates that foods can be combined in different ways to achieve healthy dietary patterns.<sup>41</sup>

## CONCLUSION

Modeling can be an important part of developing healthy eating recommendations: it provides rigor behind quantitative recommendations, ensures such recommendations are consistent with current nutritional science, and helps to tailor advice to the consumption habits of a particular country.

Development of national dietary guidance policy must consider a wide range of evidence, including nutritional science, public health priorities, the food supply and market trends, and sociodemographic and cultural profiles. Modeling can help bring all of these evidence inputs together concurrently, providing a basis for healthy eating patterns recommended in national food guides.

Many countries use food pattern modeling and/or dietary patterns analysis to help inform dietary guidance policy. Although the specific details of the methods used vary from country to country, there are common components that are used internationally. Countries can learn from each other, and, by leveraging the experience of others, continue to advance the approaches used to develop healthy eating patterns for national food guides.

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