Original Research Communications

Potassium chloride-based replacers: modeling effects on sodium and potassium intakes of the US population with cross-sectional data from NHANES 2015–2016 and 2009–2010

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ABSTRACT

Background: Sodium intake in the USA exceeds recommendations. The replacement of added sodium chloride (NaCl) with potassium chloride (KCl) provides a potential strategy to reduce sodium intake.

Objective: The purpose of this study was to quantitatively estimate changes in intakes of sodium and potassium by the US population assuming use of potassium-based NaCl replacers in top dietary sodium sources.

Methods: Data collected in the What We Eat in America (WWEIA) component of the 2015–2016 and 2009–2010 NHANES were used to identify top-ranking sources of dietary sodium among the population aged 2 y and older based on contributions from food categories aligning with the FDA draft guidance for voluntary sodium reduction. Predicted nutrient intakes were estimated in models assuming total and feasible and practical (F&P) replacement of added NaCl with KCl in foods and ingredients within the top food sources of sodium. An expert elicitation was conducted to collect information on the F&P KCl replacement of added NaCl.

Results: Using 2015–2016 consumption data, the total replacement of added NaCl with KCl in the 18 top-ranking sources of dietary sodium results in a predicted sodium intake of 2004 mg/d from the replacement of 1406 mg/d sodium with 1870 mg/d potassium as KCl. Modeled F&P replacement predicted sodium intakes of 3117 mg/d (range of 2953 to 3255 mg/d) from the replacement of 294 mg/d sodium (155 to 457 mg/d) with 390 mg/d potassium (206 to 608 mg/d). Similar results are seen with 2009–2010 data.

Conclusions: The F&P replacement of NaCl with KCl in top-ranking sources of dietary sodium modeled in this study can result in decreased sodium to a level consistent with the short-term intake goal targeted by the FDA of 3000 mg/d, with the mean potassium intake remaining in the range recommended for the apparently healthy population. *Am J Clin Nutr* 2021;00:1–11.

Keywords: dietary modeling, potassium chloride, reformulation, salt, sodium chloride replacer, sodium reduction

Introduction

Sodium intake among the US population exceeds recommendations (1), and efforts have long been underway to reduce sodium intake and the amount of sodium in foods. With the understanding that the majority of sodium in the US diet is from commercially processed and restaurant foods (2, 3), the Institute of Medicine (IOM) recommended in 2010 that the FDA set mandatory national standards to reduce the sodium content of foods in a stepwise manner, and that the food industry voluntarily reduce the sodium content of foods in advance of implementation of the standards (4).

Sodium is added to processed and prepared foods in a variety of forms including sodium chloride (NaCl) or salt and sodium-containing compounds performing a range of technical functions (4), though the predominant form of sodium in the diet is NaCl. The reduction of sodium in foods can be achieved by adding less NaCl during processing and preparation or by replacing sodium-containing additives with additives that do not contain sodium. Potassium chloride (KCl) is one of the most effective

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Supplemental Material is available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/ajcn/.

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Abbreviations used: AI, adequate intake; FDA-VSRC, US FDA Voluntary Sodium Reduction Category; F&P, feasible and practical; F&P-H, highest feasible and practical; F&P-L, lowest feasible and practical; F&P-M, most likely feasible and practical; IOM, Institute of Medicine; KCl, potassium chloride; NaCl, sodium chloride; NCHS, National Center for Health Statistics; SOI, standard of identity; SR, standard reference; WWEIA, What We Eat in America.

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NaCl replacers due to its ability to perform many of the functional roles of NaCl (5).

A primary objective in reducing sodium intake is to lower blood pressure and reduce the risk of cardiovascular disease. The public health burden of hypertension is high, with the estimated prevalence among adults in the USA in 2013–2016 at 45% (6). The increased intake of potassium resulting from use of KCl in place of NaCl could also modify the balance of sodium to potassium, which may be relevant in blood pressure control (7, 8). For certain high-risk groups, however, concern has been raised that expanding the use of KCl could lead to unsafe potassium intake.

To our knowledge, there have been no efforts to estimate the effects of KCl replacement of NaCl as a sodium reduction strategy on the intake of sodium and potassium in the USA, though the need for such an assessment is recognized (9). Outside of the USA, assessments of sodium and potassium intake have been modeled assuming a default KCl replacement across select foods (10–12). In reality, the most plausible NaCl replacement with KCl may be more varied across foods when multiple factors such as technical function, food safety, sensory attributes, and manufacturing challenges are considered. It is well recognized, for example, that although KCl tastes salty and performs some technical functions in foods, it may impart bitter, chemical, or metallic sensations that limit its use (13). Estimates of sodium and potassium intake based on KCl replacement scenarios regarded as both feasible and practical (F&P) by type of processed food would improve the precision of modeled scenarios. The objective of this analysis was to quantitatively estimate changes in nationally representative intakes of both sodium and potassium by the US population assuming the use of potassium-based NaCl replacers in top dietary sources of sodium as identified using the FDA's draft guidance on food categories for voluntary sodium reduction (14). This modeling study will provide insight on the potential reduction of sodium that is feasible with KCl replacement.

Methods

Data sources and sample population

Dietary recall data collected in the What We Eat in America (WWEIA) component of the NHANES provide nationally representative estimates of nutrient intake as well as prevalence estimates for nutrition and health status measures for the US population and are the foundation of many nutrient assessments for nutrition policy (15). Data collected in the WWEIA component of the 2015–2016 and 2009–2010 NHANES processed by the USDA were used in this modeling study. The purpose of using data from 2009–2010 was to provide a baseline for potential changes in sodium from the time when the IOM issued its recommendation to lower the nation's consumption of sodium through targets for reduced sodium in commercially processed and prepared foods (4). The 2009–2010 timeframe also aligns with the food supply the FDA reviewed when initially drafting the volunteer sodium reduction guidance (14). To provide a more contemporary assessment reflecting potential changes in nutrient intakes with the use of KCl as a sodium reduction strategy, the analysis was subsequently completed with consumption data from 2015–2016, which were the most recent data available at the time. The sample for analysis was limited to females and males aged 2 y and older, excluding breastfeeding children, who provided a reliable dietary recall meeting the minimum criteria as determined by the National Center for Health Statistics (NCHS) on day 1 of data collection (n = 7918 in 2015–2016 and n = 9042 in 2009–2010; **Supplemental Material**). The NCHS Research Ethics Review Board provided approval for the NHANES data collection. The methodological steps described below are summarized in **Figure 1**.

Identification of top sources of sodium in the US diet

Categorization of USDA food codes by the FDA Voluntary Sodium Reduction Categories.

The FDA's draft guidance for voluntary sodium reduction identifies ∼150 categories of commercially processed, packaged, and prepared foods for reduction with a target goal, where each target category represents similar foods determined to have potential for meaningful sodium reduction (16). Foods were organized by the FDA into categories in which sodium-containing ingredients have similar roles and technical potential for reduction. Foods without added sodium and foods with added sodium but of little significance to total sodium intake (e.g., infrequently consumed foods) were not assigned a target for sodium reduction in the FDA's guidance.

As part of the FDA's work on the draft Voluntary Sodium Reduction Goals efforts, the FDA categorized each 8-digit USDA food code consumed on day 1 in NHANES 2007–2010 by the population aged 1 y and older into categories representing the FDA's preliminary categorization of foods targeted for sodium reduction ("Target Categories"), with additional categories for foods not targeted for sodium reduction ("Non-Target Categories") (16).

In the current study, we used the FDA mapping file as the basis for categorizing foods consumed by the US population in the current and baseline periods (i.e., NHANES 2015–2016 and NHANES 2009–2010) into Target Categories and Non-Target Categories. We refer to the food categories used by the FDA as the FDA Voluntary Sodium Reduction Categories, or FDA-VSRC, with further distinction as "Target Categories" and "Non-Target Categories."

The databases compiled for use in this analysis (one for each NHANES survey period) identify the FDA-VSRC for each food code based on the FDA mapping file. The databases also identify the amount of sodium and potassium per 100 g food used by the USDA to process nutrient intakes for NHANES 2015–2016 and NHANES 2009–2010 (17, 18); all estimates of nutrient intakes in this analysis were based on these data. For the NHANES cycles used in this research, the USDA food composition data reflective of the foods and beverages in the food supply at that time are used to develop data for processing nutrient intakes (15). With limited exceptions (e.g., select ready-to-eat cereals; and some candies, chips, crackers, energy drinks, nutrition bars and powders, and fast-food burgers), the nutrient composition data, including sodium, are not brand specific but rather are developed to be representative of common variants of items represented by each food code (17, 18). Further details on the mappings and databases are provided in the Supplemental Material.

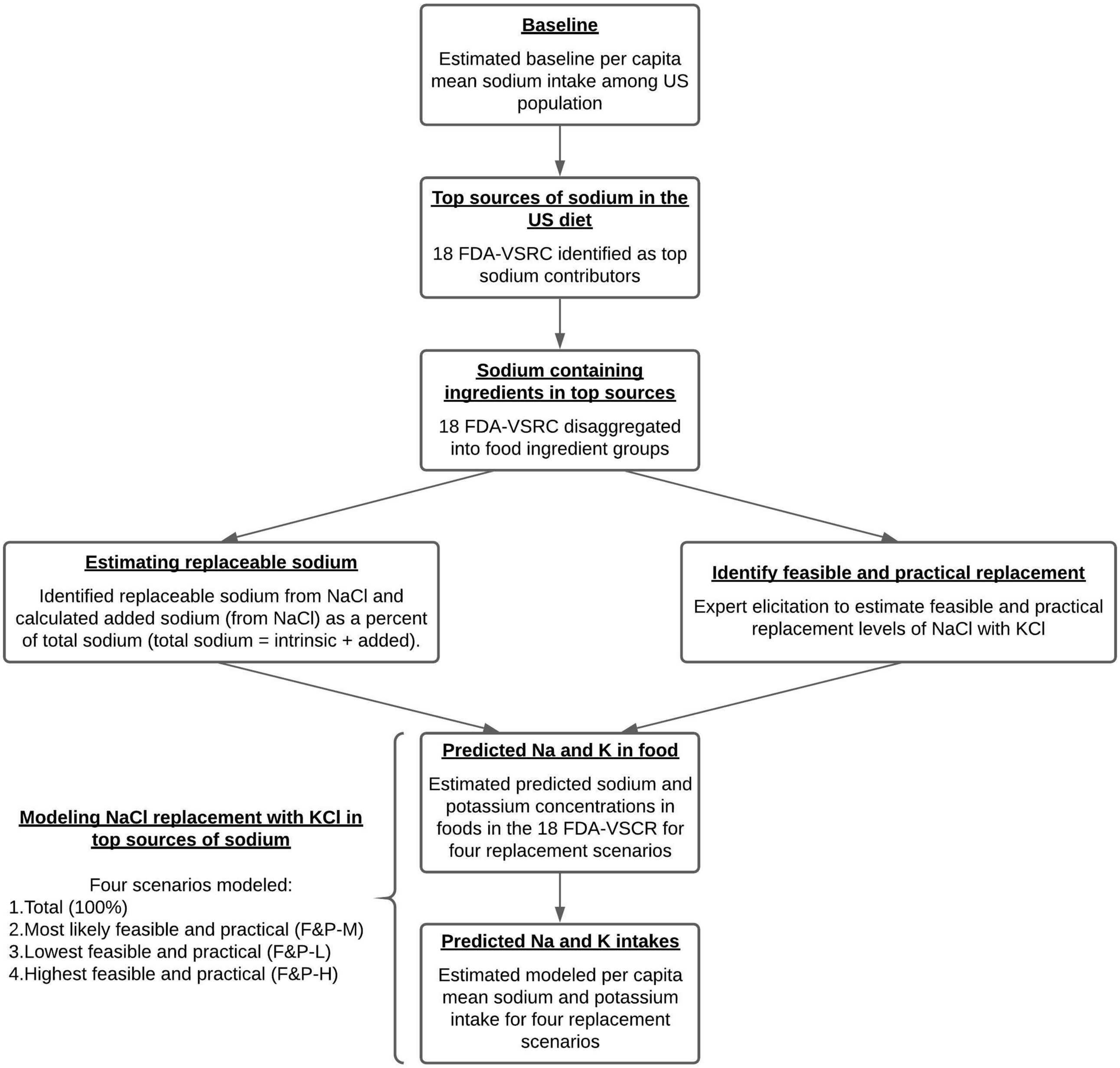

FIGURE 1 Flow chart of methodological steps to model replacement of NaCl with KCl in foods in the FDA Voluntary Sodium Reduction Categories (FDA-VSRC) accounting for top sources of dietary sodium.

Ranking of sodium contributions by the FDA-VSRC.

Using the FDA-VSRC developed for this analysis and day 1 recalls in NHANES 2009–2010 and 2015–2016, mean per capita daily intakes of sodium and potassium were calculated for the population aged 2 y and older for each of the FDA-VSRC, including Target and Non-Target Categories. Mean percent contributions of sodium intake by FDA-VSRC were estimated using the population proportion method (19), which consists of taking the ratio of the mean sodium intake from each category to the mean total sodium intake of the population. The top 20 FDA-VSRC in descending order of contribution to mean per capita total daily sodium intake in each survey period are presented in **Figure 2**. These top 20 categories accounted for 47.2% (1636 mg/d of the total sodium intake of 3466 mg/d) in NHANES 2009–2010, and 49.2% (1679 mg/d of the total sodium intake of 3410 mg/d) in NHANES 2015–2016. In both survey periods, each of the top 20 categories accounted for 1 to 7% of sodium intake (39 to 243 mg sodium per category) and the top-ranked source of sodium was grain-based dishes. Eighteen of the top 20 categories in each ranking correspond to Target Categories for Voluntary Sodium Reduction as identified by the FDA, whereas 2 categories, "Milk and similars" and "Beverages, excluding juice and milk" are Non-Target Categories. The modeling in this study focuses on the 18 top-ranking sources of sodium in each NHANES survey period that are candidates for sodium reduction, defined hereafter as the 18 Target Categories.

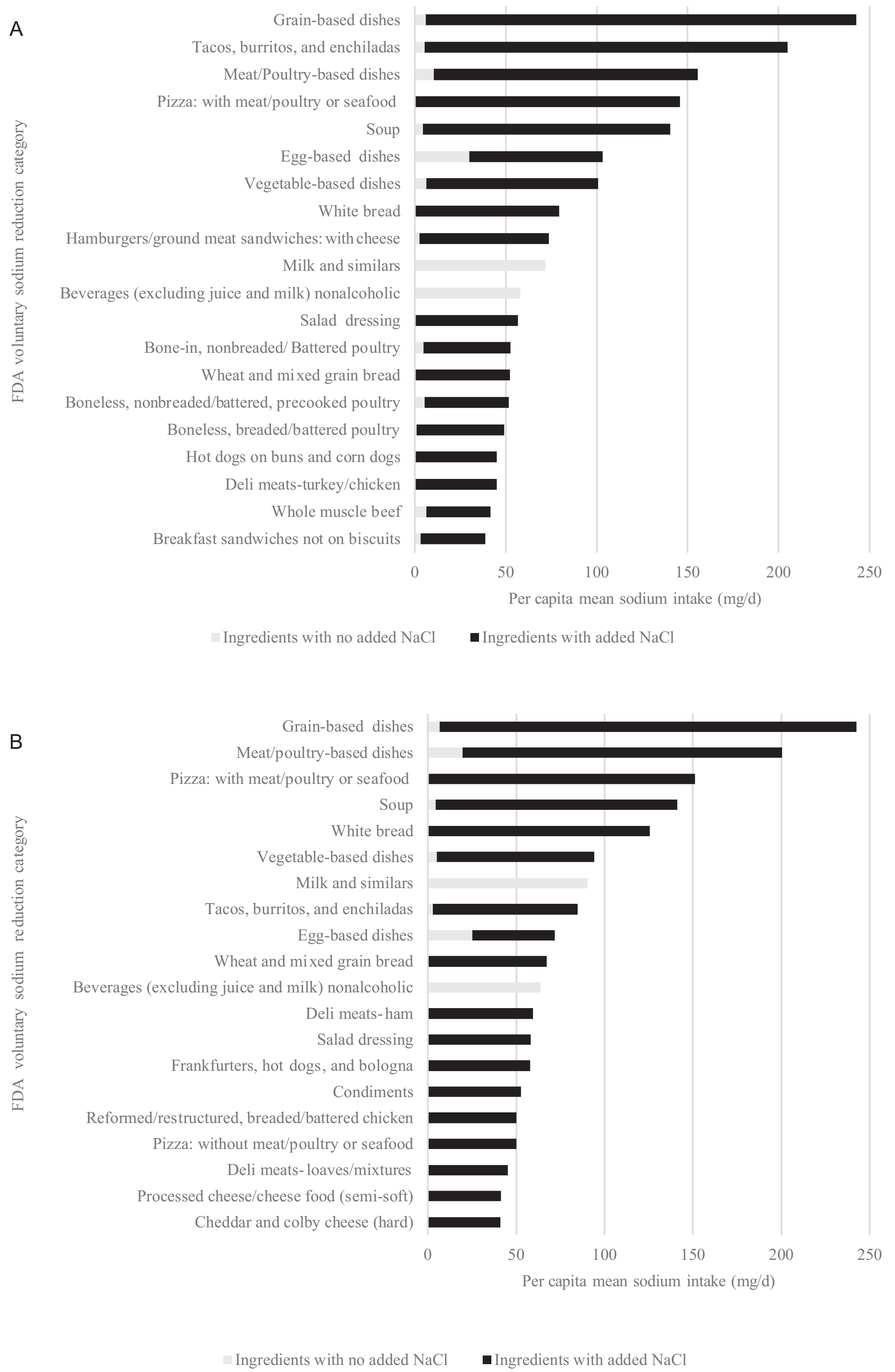

FIGURE 2 Per capita mean intake of sodium from foods in the FDA Voluntary Sodium Reduction Categories (FDA-VSRC) accounting for top sources of dietary sodium, WWEIA, NHANES 2015–2016, US population aged 2 y and older (A), and WWEIA, NHANES 2009–2010, US population aged 2 y and older (B). Sample includes all individuals aged 2 y and older (2+ y) with a valid dietary recall on day 1, excluding breastfeeding children. WWEIA, What We Eat in America.

Replacement of added NaCl with KCl

Sources of added sodium within the 18 Target Categories.

The 18 Target Categories accounting for the highest contributions to sodium intake as shown in Figure 2 formed the basis for modeling F&P replacement of added NaCl with KCl. The original study protocol specified identification of the top 10–15 food categories for use in the modeling. Given the relatively small contributions from each FDA-VSRC, the number of total categories included in the modeling was increased to 20 to capture a larger proportion of sodium intake in the models.

Each of the FDA-VSRC corresponds to a collection of USDA food codes, potentially including single component foods containing high concentrations of sodium (e.g., cheese, processed meats, condiments), food mixtures typically commercially prepared from key dietary sources of sodium (e.g., pizza or a fast-food taco), and food mixtures made from multiple ingredients, potentially including table salt added during preparation. For this analysis, each USDA food code mapped to 1 of the 18 Target Categories of interest was disaggregated into the component Standard Reference (SR) items used by the USDA to process nutrient values for each survey (20, 21). The SR items used to process nutrient data for the relevant 18 Target Category USDA food codes in each survey were, in turn, reviewed and categorized into 3 categories according to their source of sodium: *1*) no added NaCl, *2*) low/reduced sodium, or *3*) added NaCl, including salt added in typical preparation. Sources of sodium with no added NaCl include foods assumed to contain only intrinsic sodium, i.e., the naturally occurring sodium in foods such as milk, fruits, vegetables, meat, and eggs, and sodium from additives other than NaCl such as sodium bicarbonate (i.e., baking soda).

The SR items representing sources of sodium assumed to include added NaCl for each survey period were further categorized into 59 groups of similar food ingredients representing bread/grain products, condiments/sauces, dairy products, fats/oils, processed meats, soups, and spices/miscellaneous foods. For example, the bread/grain products category includes food ingredient groups for bagels, croissants, English muffins, white yeast bread, wheat/mixed grain yeast bread, dark yeast bread, pizza crust, biscuits/mixes, corn chips, plain/savory crackers, breading/coating, flour tortillas, and pie crusts. Sodium in SR items representing reduced/low sodium foods was not assumed to be replaced in the models. The food ingredient groups within each food group and additional details on the groups are presented in the Supplemental Material.

Estimating replaceable sodium.

The USDA food composition databases do not identify sodium added to commercially prepared foods specifically as NaCl versus other forms of sodium. The specific proportion of sodium present as NaCl likely varies among the specific foods represented in each food ingredient group. For this analysis, a value representative of the proportion of total sodium present in the foods included in the modeling scenarios as NaCl versus another source of sodium (i.e., intrinsic sodium or sodium from other additives) was estimated from a combination of data and information including data in the published literature for cheese and processed meats (22, 23); USDA nutrient composition data for sodium concentrations in foods with and without added salt including butter, canned vegetables, corn chips, margarine, and mayonnaise; and a review of product labels and formulations for information on the potential presence of non-NaCl sources of sodium in the remaining foods. Estimates were rounded to the nearest 5% with the exception of food ingredient groups where almost all (i.e., 99%) sodium was assumed to be added NaCl. The estimated percent of sodium present as added NaCl in each of the food ingredient groups is presented in the Supplemental Material. The food ingredient groups and the proportion of sodium within each food ingredient group assumed to be added NaCl, and therefore potentially replaceable, provided the basis for modeling the replacement of NaCl with KCl in the 18 Target Categories.

Expert elicitation to identify F&P replacement of NaCl with KCl.

Given the lack of publicly available quantitative data collected in a systematic manner on the F&P NaCl replacement with KCl for the US food supply, we conducted a structured expert elicitation to collect pertinent information from experts knowledgeable about KCl replacement in 1 or more ingredients in USDA food codes within the 18 Target Categories (24). Research on replacement strategies involving KCl has been a collaborative effort between industry and academia and for this reason, experts in both sectors were targeted for recruitment in the elicitation. For the purposes of this expert elicitation, F&P was defined as the replacement of NaCl with KCl in balances that would maintain the key roles of sodium in the food, including but not necessarily limited to technical function, food safety, shelf life, and consumer acceptance (i.e., sensory attributes). Furthermore, F&P replacement was defined as replacement that could be implemented with existing technologies and standard KCl, and where a current standard of identity (SOI) for a food exists (i.e., cheese products), the SOI would not be considered a barrier to implementation. Briefly, a total of 20 experts from academia (n = 5) and industry (n = 10) as well as private consultants (n = 5) participated in the expert elicitation and provided estimates of F&P replacement of NaCl with KCl for selected foods using a systematic series of questions administered in telephone interviews. Each expert was asked to provide estimates of low, high, and most likely F&P replacement (F&P-L, F&P-H, and F&P-M, respectively) for each food ingredient group along with an estimate of the "relative ease of implementation for achievement" of their most likely estimate on a scale ranging from 1 to 5 (1 = easy/implementation complete, 3 = typical formulation change, 5 = difficult formulation change). Values reported by each expert within a food ingredient group (2 to 7 experts per food group, with 3 or more experts responding for >90% of food groups) were aggregated by taking the mean of all responses. Where an expert provided a range of values within a specific group, the midpoint of the range was used in the calculation. In the limited situations in which an expert provided responses on subsets of queried food ingredient groups, we used the midpoint of the range of responses provided within the refined group as the response to the queried food ingredient group. The mean score for responses to the ease of implementation question was also calculated. Details on the expert elicitation, summary data collected for each food ingredient group, as well as the number of experts that provided quantitative data for each food ingredient group are provided in the Supplemental Material.

Modeling NaCl replacement with KCl in top sources of sodium

For the F&P scenario considered most likely, the mean replacement of sodium in NaCl with KCl by food ingredient group ranged from ∼14% to 35%, whereas replacement ranged from 2% to 28% in the F&P-L scenario, and 24% to 52% in the F&P-H scenario. In applying the percentage replacement of NaCl with KCl to each food code in the top 18 FDA-VSRC, nutrient composition data between 2015–2016 and 2009–2010 were reviewed to determine if NaCl replacement with KCl was evident and would necessitate modifications to the KCl replacement percentages collected in the expert elicitation to account for changes in NaCl/KCl use in the US food supply over this time period. Sodium monitoring data from the USDA indicate shifts in nutrient composition data for select products consistent with KCl replacement (25), though no changes supporting an adjustment were identified in our review of the data processed for these 2 survey periods. In both the total and F&P replacement modeling scenarios, changes in potassium concentrations per food code were estimated assuming that 1 mg of NaCl removed in the models would be replaced by 1 mg of KCl in a 1:1 molar equivalent (mg added potassium = 1.33 × mg of sodium removed in replacement scenarios for molar replacement).

Statistical analysis

Baseline estimates of per capita mean total intake of sodium, potassium, and the ratio of sodium:potassium were generated by combining each individual's reported intake of food (g) with the USDA survey-specific sodium and potassium concentration data per 100 g used to process nutrient intakes and summing over the 24-h recall period (17, 18). Mapping of the sodium and potassium concentration data was completed at the USDA food code level and did not consider food modifications. The primary outcomes were per capita mean sodium and potassium intake and the sodium:potassium ratio among the US population following replacement of NaCl with KCl in each of the 4 modeling scenarios. In the replacement scenarios, each individual's reported intake of food (g) was multiplied by the predicted sodium and potassium concentrations in the individual foods included in the 18 Target Categories, assuming 100% replacement of added NaCl with KCl (i.e., Total) or the mean most likely, lowest, and highest F&P replacement estimate (F&P-M, F&P-L, and F&P-H, respectively) derived from the expert elicitation. The ratio of sodium:potassium was calculated at the person level in each model and used to estimate the mean of the ratios. All estimates were weighted using the day 1 sampling weights provided by NCHS.

Intakes of sodium and potassium modeled assuming both total and F&P replacement of added NaCl with KCl were also developed for subpopulations by sex, age, race-ethnicity, and poverty intake ratio (select results are discussed below; complete results are presented in the Supplemental Material).

Results

Predicted intakes of sodium and potassium from modeled replacements of added NaCl with KCl

2015–2016.

In the model assuming total replacement of added NaCl with KCl as consumed by the population aged 2 y and older, 1406 mg/d of the 1679 mg/d sodium provided by foods in the 18 Target Categories is removed and replaced with 1870 mg potassium as KCl (**Table 1**). Across the total diet, the daily intake of sodium is estimated to decline by 41% to 2004 mg, and the daily intake of potassium is estimated to increase by 75% from 2502 to 4372 mg.

In the model assuming the most likely estimate of F&P replacement of added NaCl with KCl (F&P-M), 294 mg/d of sodium provided by foods in the 18 Target Categories is removed and replaced with 390 mg potassium as KCl for the population aged 2 y and older. Across the total diet, the daily intake of sodium is estimated to decline by 9% to 3117 mg, and the daily intake of potassium is estimated to increase by 16% from 2502 to 2892 mg (Table 1).

In the models assuming the lowest and highest estimate of F&P replacement of added NaCl with KCl (F&P-L and F&P-H) for the population aged 2 y and older, 155 and 457 mg/d of sodium provided by foods in the 18 Target Categories is removed and replaced with 206 mg and 608 mg potassium as KCl, respectively (Table 1). Across the total diet, the daily intake of sodium is estimated to decline by 5% and 13%, and the daily intake of potassium is estimated to increase by 8% and 24%, with the lowest and highest F&P replacement, respectively.

The predicted intakes in the model assuming the most likely estimate of F&P replacement are 3724 mg sodium and 3447 mg potassium for males aged 19 y and older, and 2755 mg sodium and 2655 mg potassium for females aged 19 years and older, with lower intakes for children (Supplemental Material).

2009–2010.

Modeling based on data from 2009–2010 provides a reference point for the potential effects of replacing NaCl with KCl. The model assuming total replacement of added NaCl with KCl removes 1415 mg/d of the 1636 mg/d sodium provided by foods in the 18 Target Categories and adds 1883 mg potassium as KCl for the population aged 2 y and older (**Table 2**). Across the total diet, the daily intake of sodium is estimated to decline by 41% to 2051 mg, and the daily intake of potassium is estimated to increase by 71% from 2638 to 4521 mg. In the F&P-M model, 301 mg/d of the 1636 mg/d sodium is removed and replaced with 401 mg potassium as KCl resulting in an estimated decline in total diet daily sodium intake by 9% to 3165 mg and an increase of potassium intake by 15% from 2638 to 3039 mg (Table 2). As shown in the Supplemental Material, predicted intakes of sodium and potassium are higher among adults relative to intakes by children, and higher among males relative to females.

Sensitivity analyses

We used the mean sodium replacement percentage from each food ingredient group in the F&P replacement scenarios; use of the median sodium replacement resulted in no meaningful

TABLE 1 Predicted sodium and potassium daily intake from total and feasible and practical replacement of added sodium chloride with potassium chloride in the 18 Target Categories, WWEIA, NHANES 2015–2016, US population aged 2 y and older

FDA Voluntary Sodium Reduction Categories[1]	Baseline		Total replacement		F&P replacement			
	Sodium	Potassium	Predicted sodium (reflects removal)	Predicted potassium (reflects addition)	F&P-M predicted sodium (reflects removal)	Range of predicted sodium (F&P-H, F&P-L)	F&P-M predicted potassium (reflects addition)	Range of predicted potassium (F&P-L, F&P-H)
Grain-based dishes	243	97	28	382	198	(173, 222)	156	(124, 190)
Tacos, burritos, and enchiladas	205	87	39	307	172	(152, 187)	131	(110, 157)
Meat/poultry-based dishes	156	88	24	264	126	(110, 141)	127	(108, 149)
Pizza: with meat/poultry or seafood	146	47	12	225	116	(98, 127)	88	(72, 110)
Soup	140	51	21	211	117	(104, 123)	83	(75, 101)
Egg-based dishes	103	40	33	134	88	(79, 97)	59	(48, 71)
Vegetable-based dishes	101	103	7	227	81	(70, 94)	129	(112,144)
White bread	79	20	7	116	67	(62, 74)	37	(28, 43)
Hamburgers/ground meat sandwiches: with cheese	74	30	11	113	60	(53, 66)	48	(39, 57)
Salad dressing	57	5	1	79	48	(41, 50)	16	(13, 25)
Bone-in, nonbreaded/battered poultry	52	25	17	72	44	(39, 48)	37	(32, 43)
Wheat and mixed grain bread	52	22	5	85	43	(39, 48)	35	(27, 39)
Boneless, nonbreaded/battered, precooked poultry	52	39	11	94	42	(37, 47)	52	(45, 58)
Boneless, breaded/battered poultry	49	26	21	62	42	(38, 44)	35	(32, 40)
Hot dogs on buns and corn dogs	45	15	8	64	36	(32, 40)	27	(22, 33)
Deli meats -turkey/chicken	45	18	11	63	38	(33, 40)	28	(25, 34)
Whole muscle beef	42	35	6	82	34	(30, 39)	45	(39, 51)
Breakfast sandwiches not on biscuits	39	11	11	48	33	(30, 36)	19	(15, 23)
FDA target categories subtotal	1679	760	273	2630	1385	(1222, 1524)	1150	(966, 1368)
All other sources subtotal	1731	1742	1731	1742	1731	1731	1742	1742
Total	3410	2502	2004	4372	3117	(2953, 3255)	2892	(2708, 3110)
Removed sodium	—	—	1406	—	294	(155, 457)	—	—
Added potassium	—	—	—	1870	—	—	390	(206, 608)
Change in total	—	—	−41%	75%	−9%	(−5%, −13%)	16%	(8%, 24%)

[1]These categories are the 18 top-ranked categories targeted for sodium reduction as specified in the FDA's draft Voluntary Sodium Reduction Categories.
All reported numbers are in mg/d with the exception of percent changes as noted.
All individuals aged 2 y and older (2+ y) with a valid dietary recall on day 1, excluding breastfeeding children. Sums by category may not equal total due to rounding.
F&P-H, highest feasible and practical; F&P-L, lowest feasible and practical; F&P-M, most likely feasible and practical, WWEIA, What We Eat in America.

TABLE 2 Predicted sodium and potassium daily intake from total and feasible and practical replacement of added sodium chloride with potassium chloride in the 18 Target Categories, WWEIA, NHANES 2009–2010, US Population aged 2 y and older

	Baseline		Total replacement		F&P replacement			
FDA Voluntary Sodium Reduction Categories[1]	Sodium	Potassium	Predicted sodium (reflects removal)	Predicted potassium (reflects addition)	F&P-M predicted sodium (reflects removal)	Range of predicted sodium (F&P-H, F&P-L)	F&P-M predicted potassium (reflects addition)	Range of predicted potassium (F&P-L, F&P-H)
Grain-based dishes	243	93	20	389	196	(170, 222)	155	(120, 189)
Tacos, burritos, and enchiladas	200	122	28	351	163	(143, 182)	171	(147, 199)
Meat/poultry-based dishes	151	44	13	228	120	(103, 132)	85	(69, 109)
Pizza: with meat/poultry or seafood	141	61	16	228	116	(103, 123)	94	(85, 112)
Soup	126	32	7	190	105	(97, 116)	60	(45, 71)
Egg-based dishes	94	90	6	207	76	(65, 87)	115	(100, 129)
Vegetable-based dishes	85	38	20	125	71	(64, 78)	56	(47, 67)
White bread	72	33	27	92	62	(57, 68)	45	(38, 52)
Hamburgers/ground meat sandwiches: with cheese	67	26	5	109	55	(50, 62)	43	(33, 49)
Salad dressing	60	31	13	93	48	(41, 53)	47	(41, 56)
Bone-in, nonbreaded/battered poultry	58	4	1	80	49	(42, 52)	16	(12, 25)
Wheat and mixed grain bread	58	16	12	77	45	(40, 50)	32	(26, 40)
Boneless, nonbreaded/battered, precooked poultry	53	15	2	82	41	(35, 43)	31	(28, 39)
Boneless, breaded/battered poultry	50	19	13	69	43	(38, 45)	29	(26, 35)
Hot dogs on buns and corn dogs	50	15	3	77	39	(33, 44)	29	(23, 37)
Deli meats -turkey/chicken	45	21	9	69	37	(32, 39)	32	(28, 39)
Whole muscle beef	41	7	19	38	35	(31, 37)	16	(13, 21)
Breakfast sandwiches not on biscuits	41	7	6	53	32	(28, 35)	18	(14, 23)
FDA target categories subtotal	1636	675	1636	2557	1335	(1172, 1469)	1075	(897, 1292)
All other sources subtotal	1831	1963	1831	1963	1831	1831	1963	1963
Total	3466	2638	2051	4521	3165	(3003, 3299)	3039	(2861, 3255)
Removed sodium	—	—	1415	—	301	(167, 464)	—	—
Added potassium	—	—	—	1883	—	—	401	(222, 617)
Change in total	—	—	−41%	71%	−9%	(−5%, −13%)	15%	(8%, 23%)

[1]These categories are the 18 top-ranked categories targeted for sodium reduction as specified in the FDA's draft Voluntary Sodium Reduction Categories.
All reported numbers are in mg/d with the exception of percent changes as noted.
All individuals aged 2 y and older (2+ y) with a valid dietary recall on day 1, excluding breastfeeding children. Sums by category may not equal total due to rounding.
F&P-H, highest feasible and practical; F&P-L, lowest feasible and practical; F&P-M, most likely feasible and practical; WWEIA, What We Eat in America.

difference in predicted intakes in either survey period (data not shown). Information collected in the expert elicitation on the ease of implementation also provides insight on which foods may be more or less likely targeted for this sodium reduction strategy. In a sensitivity analysis, changes in estimated intakes in the F&P-M scenario were modeled assuming that only those food ingredient groups with a mean "ease of implementation" score ≤3 (i.e., easy to typical formulation change) would be targeted for the replacement of added NaCl with KCl, thus eliminating replacement in bagels, croissants, soft cheese, canned meat, hot dogs, pepperoni, and pickles. Based on this more limited replacement scenario, the total sodium removed was estimated at 276 mg/d and 274 mg/d in the 2015–2016 and 2009–2010 survey periods, respectively, or ∼18–27 mg/d less than when implementation was applied to all food ingredient groups in the 18 Target Categories.

Sodium:potassium intake by the US population

The mean ratio of sodium to potassium daily intake in the US population aged 2 y and older from the diet in 2015–2016 was 1.5 and 1.4 in 2009–2010 (Supplemental Material). Under the total replacement scenario in 2015–2016, the mean ratio was estimated at 0.5, whereas under the F&P scenarios the mean ratio ranged from 1.0 to 1.3; results were similar in 2009–2010 with the mean ratio for total replacement at 0.5 and a range of 1.0 to 1.2 with F&P replacement.

Discussion

The use of KCl in place of NaCl is often identified as a possible sodium reduction strategy (4, 5, 9). In this study we modeled the impact of sodium replacement in the food supply in the timeframe of the FDA's development of the voluntary sodium reduction goals to provide a baseline of potential reduction, i.e., 2009–2010, and replicated the models using more current data, i.e., 2015–2016.

Predicted nutrient intakes in this analysis show comparable potential effects of KCl replacement in both surveys, namely a 41% reduction of sodium assuming the replacement of NaCl in foods in the top 18 Target Categories, and reductions in the range of 5 to 13% assuming F&P replacement. The comparable effects in both time periods may, in part, reflect the nearly identical baseline sodium intakes. Despite calls to reduce sodium intake, the dietary intake of sodium has remained relatively stable in the USA (26).

The 2016 FDA draft voluntary sodium reduction targets projected a decline in daily sodium intake to ∼3000 mg over 2 y with implementation of the short-term goals, and a further decline to daily intake of ∼2300 mg over 10 y with implementation of the long-term goals (14). The estimated declines in sodium intakes modeled here indicate that sodium reductions in the range of the anticipated short-term goals could be achieved with implementation of KCl replacers in the range of the most likely to the highest F&P replacement scenarios. The models also show that F&P replacement of NaCl with KCl alone cannot reduce the US population's sodium intake to a level in the range of the long-term sodium reduction goals.

The most likely F&P estimates collected in the expert elicitation conducted for this study are in line with the assumptions of 25% replacement of sodium in processed foods other than bakery goods, and 15% in bakery goods in the UK model (12), and the 20% replacement scenario assumed in modeling sodium intake produced by The Netherlands (11). The assumption of 30% replacement of NaCl with KCl in processed foods in Norway (10) aligns roughly with the upper range of the most likely F&P replacement estimates in the current study.

Reference intakes for sodium recommend a daily intake of not more than 2300 mg sodium for individuals aged 14 y and older to reduce risk of chronic disease (27). For potassium, the 2019 reference intakes include an adequate intake (AI) of 2300 to 3400 mg potassium for individuals aged 4 y and older (27). For apparently healthy individuals, the evidence was insufficient to establish a tolerable upper intake level (UL), though a high intake of dietary potassium remains a concern for individuals with impaired potassium excretion. The replacement of all added NaCl with KCl in the top sources of sodium in the current analysis with data from 2015–2016 resulted in an estimated intake of 4372 mg potassium for the US population aged 2 y and older, which is below the 4700 mg intake previously recommended for adults and the current reference intake for potassium on the Nutrition Facts panel (28, 29), though predicted potassium intakes for some subpopulations are higher. The most likely F&P replacement scenarios for the US population aged 2 y and older and subpopulations resulted in potassium intakes generally comparable to the current AIs. The modeled shifts in intake also lowered the intake ratio of sodium:potassium, which may support blood pressure control (8).

Previous models of the effects of KCl replacement on sodium and potassium intakes have assumed a single or at most 2 replacement percentages applied simultaneously across all candidate foods for replacement (10–12). The application of a KCl replacement level at the food ingredient group in the current analysis, using nationally representative food consumption data, provides more realistic estimates for the potential impact on intakes. The estimates of the lowest, highest, and most likely F&P replacement of NaCl with KCl by specific food ingredient groups through the structured expert elicitation developed for this study allow for improved prediction of the potential effects of the sodium reduction strategy in the US food supply and is a major strength of this study. The total replacement of added NaCl with KCl is an unrealistic scenario as it does not account for the acknowledged limitations on use of KCl replacers; nonetheless, it provides insight on an upper bound for a potential decrease in sodium intake and concurrent increase in potassium intake from a KCl-based sodium reduction strategy.

Limitations in the data inputs and design of the modeling study must be considered. In this study, we relied on data files developed for processing WWEIA intakes to model sodium replacement. Although such methods allow for approximations of nutrients from mixtures consistent with the framework of the WWEIA data, the USDA data were not developed with the intention for modeling nutrient replacements. Differences in ranked contributions between the time periods may reflect shifts in consumption patterns of the US population and potentially differences in data processing between the surveys. The proportions of sodium present in processed foods as NaCl were approximated with available information. Additionally, we assumed that KCl replacement of NaCl was not widely used in the food supply at baseline (i.e., 2009–2010) and in the more recent food supply (i.e., 2015–2016) based on a review of nutrient composition data. Therefore, the modeling included no adjustment for any existing use of KCl as a replacement, though continued monitoring of the food supply may allow for such adjustments in the future. In the expert elicitation, experts were asked to respond for food ingredient groups that were aggregates of individual ingredients.

Additionally, the study was designed to target NaCl replacement in only the top sources of sodium for the US population as identified from the draft FDA-VSRC. Based on the approach used by the FDA, the FDA-VSRC were matched to USDA food codes with the assumption that the food codes represent commercially prepared or packaged foods, including restaurant foods. Intake modeling in these top-ranking sources of sodium was based on assuming modified concentrations of sodium and potassium in the foods mapped by the FDA to the 18 Target Categories and do not reflect changes in the nutrient profile of food ingredients in any FDA-VSRC beyond those included in the analysis. The models also assumed that salt used in the preparation of foods in these 18 Target Categories other than foods specifically identified as from a home recipe or homemade would be replaced in part with KCl, which may be an overestimation. The cumulative sodium replacement was estimated to be the sum of contributions from each component ingredient under the same replacement scenario. It is possible, particularly in the high F&P replacement scenario, that the cumulative sodium replacement of all components assuming the highest replacement may exceed that which is realistic. The analysis was based on 1 dietary recall; whereas a single day of recall may create misclassification bias by failing to identify all consumers within each FDA-VSRC and not just those on the day of data collection, 24-h recall is a dietary assessment method known to provide valid estimates of mean population intakes, upon which our modeling and conclusions are based (30, 31). Lastly, as with any analysis based on 24-h dietary recalls, the estimates are subject to reporting bias.

In conclusion, results from this study provide important insight on the potential effects of implementing F&P use of KCl in place of NaCl at 2 points in time on the intake of sodium, potassium, and the ratio of sodium:potassium by the US population aged 2 y and older. F&P use of KCl as a replacement for NaCl in the 18 Target Categories modeled in this study could result in reductions in sodium consistent with the short-term reduction goal of daily sodium intake of ∼3000 mg targeted by the FDA and mean potassium intake in the range of recommended intakes for the apparently healthy population. The replacement of NaCl with KCl in select foods therefore provides a strategy to help lower the US population's intake of sodium, though implementation of additional strategies will be required to reach reductions in sodium intake consistent with long-term sodium reduction goals.

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The authors' responsibilities were as follows—MMM, CGS, NLT, LMB, and LAJ: designed the research; MMM, CGS, LMB, KAH, and LAJ: conducted the research; MMM, CGS, XB, and LMB: analyzed the data; MMM, CGS, and LMB: wrote the manuscript; MMM: had primary responsibility for the final content; and all authors read and approved the final manuscript. MMM, CGS, LMB, XB, KAH, and NLT are employees of Exponent, Inc., which provides scientific consulting to the food and beverage industry. The authors report no conflicts of interest. IAFNS had no role in the analysis, interpretation, or presentation of the data and results.

Data Availability

The dietary recall data described in the article are publicly available at the NHANES website: https://wwwn.cdc.gov/nchs/nhanes/ContinuousNhanes/Default.aspx. Data described in the manuscript developed for this analysis and a data code book will be made publicly and freely available without restriction at https://osf.io/wthu6/ and https://osf.io/4hnes, where the study was registered.

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