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Contribution of Food Additives to Sodium and Phosphorus Content of Diets Rich in Processed Foods

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Abstract

Objective—Phosphorus-based food additives increase total phosphorus content of processed foods. However, the extent to which these additives augment total phosphorus intake per day is unclear.

Design, setting, and measurements—In order to examine the contribution of phosphorus-based food additives to the total phosphorus content of processed foods, separate four-day menus for a low-additive and additive-enhanced diet were developed using Nutrition Data System for Research (NDSR) software. The low-additive diet was designed to conform to United States Department of Agriculture guidelines for energy and phosphorus intake (~2,000 kcal per day and 900 mg of phosphorus per day) and contained minimally-processed foods. The additive-enhanced diet contained the same food items as the low-additive diet except that highly-processed foods were substituted for minimally-processed foods. Food items from both diets were collected, blended, and sent for measurement of energy and nutrient intake.

Results—Both the low-additive and additive-enhanced diet provided ~2,200 kcal, 700 mg of calcium and 3,000 mg of potassium per day on average. Measured sodium and phosphorus content standardized per 100 mg of food was higher each day of the additive-enhanced diet as compared to the low-additive. When averaged over the four menu days, measured phosphorus and sodium contents of the additive-enhanced diet were 606 ± 125 and $1,329 \pm 642$ mg higher than the low-additive diet, respectively, representing a 60% increase in total phosphorus and sodium content on average. When comparing the measured values of the additive-enhanced diet to NDSR-estimated values, there were no statistically significant differences in measured vs. estimated phosphorus contents.

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Conclusion—Phosphorus and sodium additives in processed foods can substantially augment phosphorus and sodium intake, even in relatively healthy diets. Current dietary software may provide reasonable estimates of phosphorus content in processed foods.

Keywords

phosphorus; sodium; nutrition

INTRODUCTION

Disturbances in phosphorus homeostasis play a central role in the pathogenesis of disordered bone and mineral metabolism in persons with chronic kidney disease (CKD).¹ As a result, maintaining normal phosphorus balance is a major focus of clinical guidelines for managing bone and mineral disorders related to CKD.^{1, 2} Since dietary phosphorus intake makes up the majority of the obligate phosphorus load that the kidneys must eliminate on a daily basis to maintain phosphorus balance, diet intake has been the primary target of interventions aimed at mitigating the development of phosphorus overload in CKD patients.

Phosphorus consumption in developed countries far exceeds recommendations for daily intake.^{3, 4} In Europe and North America, an important reason for this is the nearly ubiquitous distribution of phosphorus-based food additives in commercially processed foods. Phosphorus additives are heavily utilized by the food manufacturing industry to enhance the appearance, taste and shelf-life of processed foods such as baked goods, cheese products, and meats.⁵ Consistent with this, studies have estimated that phosphorus additives can provide between 10 to 50% of total phosphorus intake per day in Westernized diets.^{6–10}

Despite the increasing recognition that phosphorus-based food additives are a significant source of phosphorus intake in Westernized diets, relatively little is known about the extent to which additives augment daily phosphorus intake in the modern era. This is because most of the available estimates in the literature come from studies conducted over 20 years ago,^{6–9} when food manufacturing practices were potentially different from today. While more recent studies have examined the phosphorus additive content of several different types of processed foods,^{11–14} these studies primarily focused on the quantity of additives in individual food items, with only one recent study focusing on the contribution of additives to total phosphorus intake per day.¹⁰ Further, most prior studies focused on additives in processed meats,^{11–14} with much less attention paid to phosphorus additives in baked products and canned items, which may be more abundant sources of phosphorus additives in processed foods.⁵ As a result, the actual contribution of phosphorus-based food additives to total daily phosphorus intake in contemporary Western diets remains poorly understood. To address this issue, we compared the measured phosphorus content of two different diets: a low-additive diet made up of fresh and minimally-processed foods, and an additive-enhanced diet consisting of the same food items and meant to provide identical caloric and nutrient contents, with the major difference being that the food items were known to be enhanced with phosphorus-based food additives.

METHODS

Separate menus for a low-additive diet and an additive-enhanced diet were developed by the Bionutrition Core of the Clinical Research Unit (CRU) at the University of Alabama at Birmingham (UAB) using the Nutrition Data System for Research (NDSR) software version 2011, developed by the Nutrition Coordinating Center, University of Minnesota, MN.^{15, 16} Each menu consisted of four separate days of food (breakfast, lunch and dinner, supplemental table 1). The low-additive menu was designed to provide 1,800 – 2,000 kcal

(15% from protein, 55 – 60% from carbohydrates, and 25 – 30% from fat) and 900 mg of phosphorus per day using fresh, non- or minimally-processed foods. These targets were meant to conform to current United States Department of Agriculture (USDA) recommendations for daily intake¹⁷. The additive-enhanced menu was designed to provide identical energy and nutrient content per day as the low-additive menu, but substituting highly-processed for minimally-processed foods (e.g., canned pineapple vs. fresh pineapple, deli chicken vs. fresh chicken breast, etc.). All study foods were purchased from local supermarkets in the greater Birmingham area. Low-additive foods were chosen by a certified research nutritionist (SSC) based on food label notices such as “no preservatives added,” “organic,” “baked fresh,” or “no processing.” Additive-enhanced foods were chosen if they were identified as “enhanced” or if phosphorus-based additives were listed on the packaging (e.g., dicalcium phosphate, pyrophosphate, sodium acid pyrophosphate, sodium aluminum phosphate, sodium phosphate, sodium tripolyphosphate, etc.).

Nutrient Analysis

In order to measure the energy and nutrient contents of the two menus, all foods from each individual day of the two menus were prepared in the metabolic kitchen of the CRU according to standard local practices and then weighed. The foods for each day were then placed into a Waring Commercial CB15 1 gallon blender and weighed again for a pre-blend weight. Foods were thoroughly blended for 20 to 30 minutes, after which a post-blend weight was taken. The three weights— total of the individual food items, pre-blend weight, and post-blend weight— were checked to ensure no loss of food occurred during the blending process. Aliquot samples for each day (half a cup) were taken from the food mixture at three different heights in the blender: the top, middle, and bottom portions. These three aliquots were frozen and sent to Covance Laboratories Inc. (Madison, WI) along with the total food mixture volume and weight to determine the energy and nutrient contents for each day of the two menus. The fat content was determined as follows: samples were hydrolyzed with hydrochloric acid, after which the fat was extracted using ether and hexane, and the extract was filtered through a sodium sulfate column.¹⁸ The solvent was then evaporated from the remaining extract and the fat was dried and weighed.¹⁸ The carbohydrate content was calculated using the total carbohydrate by difference method.¹⁹ The protein content was determined by the Dumas Method.²⁰ Nutrient elements (calcium, phosphorus, potassium, and sodium) were determined as follows: food samples were ashed at high temperature, digested in acid, and then nutrient elements were measured by inductively coupled plasma emission spectrometry.²¹ Total energy and nutrient contents of the foods for each menu day were based upon the mean value of the three aliquot measurements, expressed as kcal/100 g or mg/100 g food. Total energy and nutrient intake per day was then derived by multiplying these values by the total grams of food prepared for each day. Total energy intake from protein, carbohydrates and fat was estimated using established conversion factors—protein: 4 kcal/g, carbohydrates: 4 kcal/g, and fat: 9 kcal/g. Percent of total kilocalories provided from protein, carbohydrates, and fat was calculated as follows: (kcal from nutrient/total kcal) $\times$ 100. This study was reviewed and approved by the Institutional Review Board at UAB.

Statistical Analysis

Differences in the nutrient contents of each diet were compared using Student's *t*-test. Generalized linear models were used to compare energy-adjusted mean nutrient contents of the two diets. A two-tailed *P*-value < 0.05 was considered statistically significant. All analyses were done using SAS version 9.2 (SAS Institute, Cary, NC).

RESULTS

Table 1 depicts food items for each menu from a representative day (a full listing of the menus for each day is provided in supplemental Table 1). As per study design, the food items of the two menus were virtually identical, with the only major differences being the use of highly-processed foods in the additive-enhanced diet (e.g., canned, frozen foods) as compared to fresh or minimally-processed foods in the low-additive diet.

Table 2 compares the measured energy and nutrient contents of the low-additive diet and the additive-enhanced diet, standardized per 100 grams of food, for each of the four menu days. Although individual days displayed some variability in total energy, protein, carbohydrate, and fat content per 100 grams of food, overall, these values were similar for each day. More consistent differences were noted in the measured calcium, phosphorus, sodium and potassium contents between the two diets. In general, the additive-enhanced menus had lower amounts of calcium and potassium per 100 grams of food than the low-additive menus. In contrast, the phosphorus and sodium contents of additive-enhanced foods were substantially higher than low-additive foods, with the differences ranging from 30 – 40%, on average.

Total sodium, phosphorus, calcium and potassium contents of the two diets per day are depicted in Figure 1. Calcium and potassium contents varied in some, but not all, of the menu days (Figures 1A and 1B), with the direction of the variation being inconsistent. In contrast, total sodium content was consistently higher each day of the additive-enhanced menu as compared to the low-additive menu (Figure 1C), with the magnitude of the difference ranging from as low as 703 mg to as high as 1,750 mg of sodium. Similarly, total phosphorus content was significantly higher each day of the additive-enhanced menu as compared to the low-additive menu (Figure 1D), with the magnitude of the difference ranging from 483 mg to 790 mg of phosphorus. When the phosphorus and sodium contents of the two diets were averaged over the 4 menu days, the additive-enhanced diet contained on average 606 ± 125 mg more phosphorus ($P < 0.001$ for difference) and $1,329 \pm 642$ mg more sodium ($P = 0.02$ for difference) than the low-additive diet (Table 3). No statistically significant differences were observed in the four-day averaged total caloric, calcium, or potassium contents of the two diets.

Table 3 also depicts the contents of the diets (averaged over the 4 menu days) estimated by NDSR software as compared to the actual measured values. When comparing the estimated content of the low-additive diet to the measured content of the low-additive diet, there were no significant differences in any of the components except for the phosphorus content, which was slightly higher in the measured as compared to estimated value (1070 ± 58 vs. 924 ± 82 mg, $P = 0.03$). This latter difference was attenuated after accounting for differences in the measured vs. estimated calories of the low-additive diet (energy-adjusted phosphorus content of additive-enhanced menu 1041 ± 78 mg, energy-adjusted phosphorus content of low-additive menu 954 ± 80 mg, $P = 0.12$). Similarly, when comparing the estimated content of the additive-enhanced diet to the measured content, there were no statistically significant differences in total energy, calcium, phosphorus, sodium or potassium content, even after accounting for differences in the total caloric intake.

DISCUSSION

Dietary restriction of sodium and phosphorus are key components of nutritional counseling in individuals with CKD. As underscored by the results of the current study, however, achieving these goals is immensely complicated by the presence of sodium- and phosphorus-based additives in processed foods. Even in the relatively healthy diet created

for this study, additives in processed foods augmented total phosphorus and sodium content by ~60% per day. These findings highlight the magnitude of the barrier that food additives present in lowering sodium and/or phosphorus intake in CKD patients.

A number of studies have previously documented that phosphorus-based food additives can substantially augment the total phosphorus content of staple items of Westernized diets, particularly processed meats.^{11–14} However, these prior studies almost exclusively focused on the phosphorus content of individual food items and not full-day menus, making it difficult to determine the extent to which additive-enhanced foods contribute to total phosphorus intake per day. This is important in that studies from our group have shown that additive-rich foods like processed meats and dark colas are consumed relatively infrequently in comparison to other more energy-dense items in the general population.^{22, 23} Therefore, it is possible that, while rich in additives, these foods may not be consumed in high enough quantities to substantially augment total phosphorus intake per day. The results of the current study argue against this possibility by demonstrating that phosphorus additives in commonly consumed foods can substantially increase daily phosphorus intake—even in a balanced 2,200 kcal/day diet such as the one in this study—with important implications for the management of bone and mineral metabolism in CKD patients. For example, similar to what has been shown by other investigators,^{11, 14} using published phosphorus binding capacities of a 667 mg tablet of calcium acetate, a 800 mg tablet of sevelamer, and a 750 mg tablet of lanthanum,^{24–26} a hypothetical patient consuming the additive-enhanced diet in this study would need to take 18 extra tablets of calcium acetate, 23 extra tablets of sevelamer hydrochloride, or 5 extra tablets of lanthanum carbonate over the course of each day to bind just the excess phosphorus found in the additive-rich foods. Similarly, using published phosphorus clearance data for a standard hemodialysis session lasting four hours using a high-flux, high-efficiency dialyzer, a blood flow of ~400 ml/min and a dialysate flow of ~500 ml/min,²⁷ and assuming nearly 100% intestinal absorption of inorganic phosphorus from additives, 12 extra hours of hemodialysis a week would be required to remove just the extra phosphorus found in the additive-enhanced diet prepared for this study.

One other recent study examined differences in the total phosphorus content of an additive-free vs. an additive-containing diet.¹⁰ Using a commercially-available dataset of grocery sales in northeast Ohio from 2009 to 2010, León et al. selected the top five best-selling food products containing phosphorus additives within fifteen general food categories (prepared frozen foods, dry food mixes, packaged meats, etc.) and matched them one-to-one to similar products without phosphorus additives. Both additive-containing and non-additive-containing products were then purchased from local food stores and sent for measurement of phosphorus content after preparation of the food items according to packaging labeling. Sample meals were then developed using analyzed matched foods to approximate the mean calorie, protein, carbohydrate and total fat intake of US adults as estimated by the 2007 to 2008 National Health and Nutrition Survey *What We Eat in America* study. The main finding of their study was that, as compared to additive-free foods, additive-containing foods were estimated to contribute 736 ± 91 mg (or 70%) more phosphorus per day. This is in line with our results, suggesting our findings do not merely reflect the phosphorus additive content of foods local to our region, but instead are likely reflective of the upper extreme of phosphorus additive content in the broader US food supply.

Given that sodium is commonly complexed with phosphorus in food additives, it is not surprising that along with total phosphorus intake, additives in the processed foods chosen for this study also substantially increased total sodium content. Sodium additives almost completely account for the excess intake of sodium in many populations, particularly in Western countries where 75% of sodium intake is estimated to come from sodium added to processed foods.²⁸ While prior studies have documented high amounts of sodium in fast and

convenience foods,^{28–30} it is important to note that the diet created for the purposes of this study was relatively healthy, meeting USDA guidelines for total energy, fat, and carbohydrate intake per day. Nonetheless, with just the substitution of highly- for minimally-processed foods, total daily sodium content averaged nearly 3.5 grams, far above the current USDA tolerable upper limit of 2.3 grams per day. This highlights the reality that, in addition to phosphorus, CKD patients may be consuming substantially higher quantities of sodium than appreciated, even in “healthy” appearing diets, and that any serious effort to reduce sodium intake in these patients must include a discussion of where and what kinds of foods are being purchased for consumption at home.

An unexpected finding of this study was that the NDSR-estimated phosphorus content was nearly identical to the measured phosphorus content of the foods, both in the low-additive diet and the additive-enhanced diet. Prior investigators have reported that current dietary software programs such as NDSR—which utilizes the USDA Nutrient Data Laboratory as its primary source of nutrient values and nutrient composition—do not adequately account for phosphorus additives in processed and fast foods and thus, may underestimate the true phosphorus content of these foods.^{7, 31–33} In contrast, we found that the estimated phosphorus contents of the processed foods chosen for this study were nearly identical to the actual measured values, suggesting that NDSR-derived estimates of phosphorus content may provide reasonably accurate assessments of phosphorus intake. As most food frequency questionnaires and/or 24-hour dietary recalls used in population-based research rely on USDA Nutrient Data Laboratory estimates, further studies will need to determine whether phosphorus intake estimates derived from these instruments demonstrate similar degrees of accuracy in capturing the phosphorus content of processed foods.

It should be noted that the diets were specifically designed to accentuate the differences between a low-additive and an additive-rich diet by preferentially choosing minimally-processed foods in the former and highly-processed foods in the latter. Because of this, the results may not be representative of more real-world diets in which individuals are consuming a mixture of both fresh and processed foods, potentially over-estimating the contribution of processed foods to phosphorus intake in typical Western diets. At the same time, given that we designed the diet to conform to USDA recommended guidelines for fat, protein, carbohydrate and phosphorus intake, it is also possible that we underestimated the true impact of processed foods on phosphorus content in more typical “convenience” diets consumed by increasing numbers of Americans, which may not meet the USDA guidelines. Other limitations of our study include the fact that we sampled a relatively limited number of unique food groups between the two diets, and we measured nutrient contents during only one time of year (given potential for changing phosphorus content of food throughout the year).³⁴ In addition, we did not have any data on the differential measurement of inorganic vs. organic phosphorus in individual foods.¹¹

In conclusion, food additives substantially augment sodium and phosphorus contents of modern American diets. Future studies will need to examine the physiological impact of this excess additive intake on individuals with both normal and decreased kidney function to understand the public health implications of these findings.

PRACTICAL APPLICATION

Sodium- and phosphorus-based food additives in processed foods represent large barriers in restricting dietary intake of sodium and phosphorus, even in relatively healthy diets. Any serious attempt to restrict sodium and/or phosphorus intake in patients with CKD will require a detailed inventory of where and what kind of foods are purchased by patients.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1A **Figure 1B**

Figure 1C **Figure 1D** **Figure 1.**

Average measured content of calcium (1A), potassium (1B), sodium (1C), and phosphorus (1D) in the low-additive (blue bars) vs. additive-enhanced (red bars) diets per day. Bars represent means and vertical hatchets represent standard deviation.

Table 1

Representative example of food item selections from one menu day of the low-additive diet as compared to the additive-enhanced diet.

Low-additive menu	Additive-enhanced menu
Breakfast	Breakfast
Corn Flakes (Kellogg's Brand), 1.75 cups	Special K Low Carb Lifestyle (Kellogg's Brand), 1.5 cup
Low fat soy milk (Horizon Organic), 8 fl oz	Skim Milk (Dairy Fresh), 8 fl oz
Fresh Pineapple, 1.5 cups	Canned Pineapple (Dole), 12 oz
Lunch	Lunch
Pita Bread (Toufayan Bakeries), 1 medium	Pita Bread, wheat (Kangaroo), 1 medium
Chicken breast, fresh (Publix Greenwise), 45 g	Chicken, Deli (Oscar Meyer), 45 g
Mayonnaise, regular (Kraft), 12.4 g	Mayonnaise, regular (Kraft), 12.4 g
Nectarine, fresh, 1 medium	Canned peaches (Del Monte), 4 oz
Buttered, light popcorn (Orville Redenbacher), 1.6 oz	Natural, light popcorn (Orville Redenbacher), 1.6 oz
Jolly Rancher candy (Hershey), 5 pieces	Jolly Rancher candy (Hershey), 5 pieces
Dinner	Dinner
Tilapia (Publix brand, frozen), 1 filet (4 oz)	Canned salmon (Chicken of the Sea), 1 can (2.8 oz)
White rice (Minute Rice), 4.4 oz	White rice (Uncle Ben's), 8.8 oz
Butter, regular (Glenview Farms), 5 g	Butter, regular (Glenview Farms), 10 g
Carrots, fresh, 1 cup	Canned carrots (Del Monte), 8 oz
Iceberg lettuce, 1/8 head wedge	Iceberg lettuce, 1/8 head wedge
Olive oil (Pompeian), 2 tablespoons	Olive oil (Pompeian), 2 tablespoons
Apple cider vinegar (Publix brand), 1 tablespoon	Apple cider vinegar (Publix brand), 1 tablespoon
Organic white roll (Whole Foods Market), 1 small	Biscuit, frozen (Pillsbury), 1 medium
Jello, regular (Kraft), 1 container (4 oz)	Jello, regular (Kraft), 1 container (4 oz)

Table 2

Energy and nutrient contents (standardized per 100 grams of food) of the low-additive versus additive-enhanced menu per day. Results are depicted as means ± standard deviation.

Variable	Day 1				Day 2				Day 3				Day 4			
	Low-Additive Menu	Additive-enhanced Menu	Low-Additive Menu	Additive-enhanced Menu	Low-Additive Menu	Additive-enhanced Menu	Low-Additive Menu	Additive-enhanced Menu	Low-Additive Menu	Additive-enhanced Menu	Low-Additive Menu	Additive-enhanced Menu	Low-Additive Menu	Additive-enhanced Menu	Low-Additive Menu	Additive-enhanced Menu
Calories (kJ/100 g)	153 ± 10	140 ± 7	156 ± 3	153 ± 3	108 ± 3	99 ± 4	133 ± 4	119 ± 1*								
Protein (g/100 g)	6.4 ± 0.3	4.2 ± 0.1*	5.0 ± 0.2	5.5 ± 0.4	4.7 ± 0.2	3.8 ± 0.2*	6.4 ± 0.2	6.3 ± 0.2								
Carbohydrates (g/100 g)	22.8 ± 1.6	22.6 ± 1.8	23.8 ± 0.5	22.6 ± 0.7	16.3 ± 0.6	13.6 ± 1.1*	18.7 ± 0.9	13.2 ± 0.4 [†]								
Fat (g/100 g)	4.03 ± 0.4	3.6 ± 0.1	4.5 ± 0.2	4.5 ± 0.1	2.7 ± 0.1	3.3 ± 0.1*	3.7 ± 0.2	4.6 ± 0.2*								
Calcium (mg/100 g)	52.5 ± 0.6	47.6 ± 1.7*	58 ± 1.2	48.3 ± 1.3 [†]	36.1 ± 0.3	26.1 ± 0.5 [†]	36.1 ± 0.3	30.8 ± 0.9 [†]								
Phosphorus (mg/100 g)	70 ± 0.5	99.5 ± 0.9 [†]	67 ± 0.6	111 ± 3.0 [†]	51.3 ± 0.3	70.2 ± 1.0 [†]	68.9 ± 0.3	97.7 ± 2.9 [†]								
Sodium (mg/100 g)	139 ± 2	221 ± 4.5 [†]	124 ± 1.5	162 ± 2.3 [†]	135 ± 2.6	177 ± 1.5 [†]	84.3 ± 2.6	194 ± 6.5 [†]								
Potassium (mg/100 g)	253 ± 5.1	180 ± 5.6 [†]	150 ± 2.6	209 ± 6.6*	173 ± 5.5	162 ± 3.8*	197 ± 4.5	150 ± 10.2*								

* $P < 0.05$ comparing low-additive menu to additive-enhanced menu

[†] $P < 0.001$ comparing low-additive menu to additive-enhanced menu

Table 3

Estimated and measured energy and nutrient content of the low-additive and additive-enhanced diets averaged over the four menu days. Results are presented as means $\pm$ standard deviation.

Variable	Low-Additive Diet		Additive-Enhanced Diet	
	Estimated Values*	Measured Values	Estimated Values*	Measured Values
Calories (kJ/day)	1932 $\pm$ 171	2294 $\pm$ 258	1910 $\pm$ 195	2278 $\pm$ 323
% fat	24 $\pm$ 2	24 $\pm$ 2	28 $\pm$ 0.1	28 $\pm$ 5
% protein	16 $\pm$ 3	17 $\pm$ 3	16 $\pm$ 1	16 $\pm$ 4
% carbohydrates	62 $\pm$ 1	59 $\pm$ 2	58 $\pm$ 2	56 $\pm$ 9
Calcium (mg/day)	656 $\pm$ 166	732 $\pm$ 232	654 $\pm$ 169	677 $\pm$ 178
Phosphorus (mg/day)	924 $\pm$ 82	1070 $\pm$ 58 [§]	1426 $\pm$ 275	1677 $\pm$ 167 [†]
Sodium (mg/day)	2271 $\pm$ 620	2068 $\pm$ 633	3727 $\pm$ 731	3396 $\pm$ 651 ^{††}
Potassium (mg/day)	2785 $\pm$ 946	3252 $\pm$ 758	2919 $\pm$ 775	3152 $\pm$ 580

* Estimated by Nutrition Data System for Research software version 2011

[†] $P < 0.001$ comparing measured values in the low-additive diet to measured values in the additive-enhanced diet

^{††} $P < 0.05$ comparing measured values in the low-additive diet to measured values in the additive-enhanced diet

[§] $P < 0.05$ comparing estimated values in low-additive diet vs. measured values in low-additive diet