ORIGINAL RESEARCH

Patterns of Fruit and Vegetable Intake in Adults With and Without Chronic Kidney Disease in the United States

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Objective: To characterize patterns of fruit and vegetable (F&V) intake in US adults with and without chronic kidney disease (CKD).

Methods: We used 24-hour dietary recall data from multiple cycles of the National Health and Nutrition Examination Survey spanning 3 groups from 1988 to 2018 (1988-1994; 2003-2010; 2011-2018). We categorized F&Vs based on food processing and phytochemical content. We assessed patterns of F&Vs using latent class analysis and compared intake patterns across the 3 temporal cohorts and CKD status using weighted multinomial logistic regression.

Results: Four similar patterns of F&Vs emerged in each cycle: Overall Low Intake, High Unprocessed, High Ultra-Processed, and Moderate Processed F&Vs. The Overall Low Intake pattern was most prevalent in all cohorts and CKD groups. After adjustment for demographic variables and selected health conditions, participants with compared to without CKD were more likely to be classified as Overall Low Intake in each cohort, although this was not significant in the National Health and Nutrition Examination Survey 2011-2018.

Conclusions: Low consumption of F&Vs was more common in patients with CKD. Longitudinal studies are needed to determine if low intake is a risk factor for, or response to, CKD.

Keywords: chronic kidney disease; fruits; NHANES; patterns of intake; vegetables

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Introduction

CHRONIC KIDNEY DISEASE (CKD) is a common health condition affecting approximately 13% of the US population.[1] Preventive dietary measures are important to many patients with CKD, but empiric evidence to guide these measures is limited.[2,3] Available dietary guidelines for patients with CKD primarily focus on recommended nutrient intakes (e.g., sodium, potassium, and phosphorus) with less emphasis on whole foods, such as fruits and vegetables (F&Vs).[4,5] To enable clear and translatable recommendations for patients with CKD, more studies focused on whole foods and food patterns are needed.

Many health benefits of F&Vs are related to their biological constituents including vitamins, minerals, dietary fiber, and phytochemicals.[6,7] Phytochemicals in F&Vs are naturally occurring compounds with antioxidant and anti-inflammatory activities,[6] and are categorized into several different classes including polyphenols (e.g., anthocyanin and flavones), glucosinolates (e.g., glucoraphanin), and carotenoids (e.g., lutein and zeaxanthin).[8] Health benefits may also be related to minerals in F&Vs, such as potassium. Often patients with CKD limit intake of F&Vs to avoid excess dietary potassium because they may be at risk for dangerous elevations in blood potassium, or hyperkalemia. However, dietary potassium restriction has not been shown to be clearly beneficial in patients with CKD and clinically important hyperkalemia is unlikely in patients with only mild to moderate CKD.[9] Dietary potassium restriction may inadvertently lower consumption of many healthy foods such as F&Vs in patients with CKD. As such, the 2020 update of Clinical Practice Guideline for Nutrition in CKD from the National Kidney Foundation and the Academy of Nutrition and Dietetics cite the need for further evidence on food patterns and F&V intake in CKD.[10]

To explore the relationship between CKD and F&V intake, we characterized patterns of F&V intake in participants of National Health and Nutrition Examination Survey

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(NHANES) assessing similarities or differences between people with and without CKD. Defining F&V intake patterns in this way will allow further study of the role of F&V patterns in relation to CKD outcomes to improve guidelines and dietary recommendations for patients with CKD.

Methods

Survey Design and Population

We established 3 cohorts to represent different time periods for assessing patterns of F&V intake: NHANES III (Third National Health and Nutrition Examination Survey; 1988-1994), Continuous NHANES cycle 2003-2010, and Continuous NHANES cycle 2011-2018. NHANES is a cross-sectional, nationally representative data set based on self-reported and measured data from a weighted sample of the noninstitutionalized US population. It is conducted by the National Center for Health Statistics (NCHS).[11] NHANES III was the last periodic survey. It was then followed by Continuous NHANES, which is conducted in recurring 2-year cycles.[12] The de-identified and publicly available datasets of NHANES include questionnaires, standardized physical examination and laboratory data including weight, height, blood and urine measurements, medical history, and 24-hour dietary recall interviews. In this study, we included data from adults 18 years of age and older with complete, valid dietary recall data in each of these NHANES cycles. This study was determined to be nonhuman subject research by the University of Virginia Institutional Review Board for Health Sciences Research.

Exposure and Covariates

Our primary exposure variable was participants' CKD status. CKD was defined as creatinine-based estimated glomerular filtration rate (eGFR) of lower than 60 mL/min/1.73 m^2, or albuminuria, defined as urine albumin to creatinine ratio >30 mg/g. In NHANES III, serum creatinine was measured using a kinetic rate Jaffe method which was recalibrated to standardized serum creatinine.[13] Serum creatinine was recalibrated for the 2005-2006 cycle as recommended in the dataset documentation.[14] The 2009 CKD Epidemiology Collaboration (CKD-EPI) equation was used to calculate eGFR from the standardized creatinine values.[15] Covariates such as medical comorbidities and demographics were self-reported. Body mass index (BMI) and waist circumference were assessed by physical examination in the NHANES mobile examination center.

Pattern of Fruit and Vegetable Intake Analysis

The primary outcome in our study was patterns of F&V intake based on participant's self-reported dietary intake.

Assessment of Dietary Intake and Grouping of Foods

The primary diet assessment method in NHANES was 24-hour dietary recall interview. One recall per participant was conducted in NHANES III and two recalls were performed in continuous NHANES. When two recalls were available, we averaged all variables across the two recalls before further analysis. We used the data from the individual food files where each individual food consumed is represented by a food code (DRPFCODE) and description.[16] We evaluated different types of F&V foods consumed by participants including citrus fruits, fresh citrus fruit juice (100%), dried fruits, berries, other fruits, other fresh fruit juices (100%), potato and other starchy vegetables, different types of cabbage, dark green vegetables, deep-yellow vegetables, tomatoes, and other vegetables. Mixed dishes containing F&Vs were not considered.

We categorized foods first into: 1) unprocessed, 2) minimally processed and processed (minimally/processed), and 3) ultra-processed F&Vs following general principles in the NOVA food classification system.[17,18] According to NOVA, unprocessed foods are natural foods obtained directly from plants (or animals) without any alterations. Minimally processed foods involve cleaning, removal of inedible parts, drying, fermentation, cooling, or freezing. Processed foods are products derived from natural foods and are recognized as a version of the original foods. Ultra-processed foods are made from substances extracted from foods, synthesized in laboratories, or derived from food constituents.[18] Where adequate information about a specific food was not available, we assumed the product was minimally processed or processed. We also classified each F&V based on their phytochemical content, obtaining four groupings: glucosinolate-rich; carotenoid-rich; polyphenol-rich; and starchy vegetables. Information on the phytochemical content of F&Vs was obtained from published literature and expert consensus to determine classification[19,20] (Supplemental Material). Pairwise grouping of processing classification and phytochemical content of each item resulted in 12 potential groups.

Dietary Pattern Analysis

We coded consumption in each of the 12 groups as 'none' or 'some' based on the available dietary recalls. For instance, in Continuous NHANES when 2 recalls were available, 'none' or 'some' referred to a 2-day period. We collapsed food groupings with less than 5 percent consumption with a neighboring group. This resulted in collapsing glucosinolate-rich ultra-processed F&Vs with glucosinolate-rich minimally/processed F&Vs, and unprocessed starchy vegetables with minimally/processed starchy vegetables, yielding 10 final F&V categories for latent class analysis (LCA).[21,22]

LCA was conducted using the LCCA package in R (R 3.0.1), separately for NHANES III and Continuous NHANES cycles of 2003-2010 and 2011-2018. In Continuous NHANES, we used unconstrained LCA models considering cycles (NHANES 2003-2010 and NHANES 2011-2018) as group variables. This allowed us to capture

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potential qualitative differences in patterns across the time periods. The optimal number of classes between 2 to 7 was determined by evaluating convergence and goodness-of-fit statistics [i.e., the Bayesian information criterion (BIC)] along with clinical interpretability. Based on all criteria, we selected an optimal model with 4 classes translating to F&V patterns. Participants were assigned to one of the 4 patterns based on the group with the highest posterior probability. To better understand if the intake pattern differences between NHANES III and Continuous NHANES were influenced by the use of two versus one recall, we also performed LCA using only one 24-hour dietary recall for Continuous NHANES in sensitivity analyses.

Assessment of Objective Biomarkers of Intake

To assess face validity of our F&V patterns, we assessed clinical measures, diet nutrient intake and serum biomarkers, where available, across groups. Dietary nutrients were assessed from the 24-hour dietary recall interviews by NHANES using the Food and Nutrient Database for Dietary Studies developed by the US Department of Agriculture. In Continuous NHANES when 2 dietary recalls were available, we averaged nutrient intake across the 2 days. Serum carotenoids, including α-carotene, β-carotene, β-cryptoxanthin, lycopene, and lutein/zeaxanthin as well as serum levels of vitamins A, E, and C, were available in NHANES III and Continuous NHANES cycles 2003-2004 and 2005-2006. Highly skewed biomarkers were log transformed and tested across F&V patterns by analysis of variance accounting for survey design.

Association Between CKD and Patterns of Fruits and Vegetable Intake

We evaluated the association between patterns of F&V intake and prevalent CKD in each cohort using multinomial logistic regression, with and without adjusting for covariates (e.g., age, sex, race, waist circumference, diabetes, and hypertension). We computed the adjusted and unadjusted odds ratios and corresponding 95% confidence intervals (CIs) for association of CKD status with each F&V pattern relative to the Overall Low Intake pattern. As the odds ratios are for each pattern relative to a reference pattern, we also re-expressed the predicted marginal probabilities to provide a more global comparison of the pattern differences in CKD and non-CKD groups. These marginal probabilities represent the average of the model-predicted probabilities for the full weighted population calculated if all individuals had CKD compared to those if all individuals did not have CKD. Other covariates in the model were assigned their observed level for calculating these probabilities.[23] Due to uncertainty in some pattern assignments with relatively low classification accuracy (i.e., entropy), we performed a one-step analysis that directly modeled the covariate effects in the LCA classification as a sensitivity analysis. This approach can yield more robust results when entropy is low.[24] All statistical analyses accounted for the complex survey design of NHANES III and Continuous NHANES using sampling weights.

Results

Study Population, Clinical, and Dietary Characteristics

Across years, a total of 13.6% (NHANES III) to 15.2% (Continuous NHANES 2011-2018) of the population was estimated to have CKD. When CKD was defined only by eGFR$<$60 mL/min/1.73 m^2 (i.e., stage G3a or higher) 6.5% in NHANES III, 6.6% in Continuous NHANES 2003-2010, and 6.9% in Continuous NHANES 2011-2018 would have CKD, indicating a large fraction with albuminuria only, particularly in later cohorts. The average age was 58.5 $\pm$ 19.5 years in CKD and 41.0 $\pm$ 15.4 years in non-CKD participants in NHANES III; 60.3 $\pm$ 18.6 years in CKD and 43.4 $\pm$ 16.0 years in non-CKD participants in Continuous NHANES 2003-2010; and 60.0 $\pm$ 18.0 years in CKD and 44.6 $\pm$ 17.0 years in non-CKD participants in Continuous NHANES 2011-2018. Across all cohorts, participants with CKD were more likely to be older, female, and Black, and to have higher BMI, hypertension, and diabetes (Table 1). Total energy intake was significantly higher in non-CKD than CKD participants in all three NHANES datasets ($P < .0001$). However, in NHANES III and Continuous NHANES 2003-2010, percentage of calories from protein ($P < .0001$ and $P = .007$, respectively) and carbohydrate ($P = .005$ and $P < .0001$, respectively) was significantly higher in participants with CKD. In most cycles, unadjusted macronutrient densities of fiber, phosphorus, sodium, and potassium were higher in participants with CKD, but not dietary carotenoids (Table 1).

Patterns of Fruits and Vegetable Intake

Patterns of F&Vs are depicted in Figure 1. Classification diagnostics revealed that the mean membership posterior probabilities ranged from 0.60 $\pm$ 0.13 to 0.84 $\pm$ 0.18 across patterns and cohorts, with mean posterior probabilities above 0.8 for 4 out of 12 pattern/cohort combinations (Table S1). Entropy in the selected model was 0.59 in NHANES III and 0.55 in the combined Continuous NHANES models.

Overall, within the three NHANES datasets, we identified one pattern of overall low F&V consumption (Overall Low Intake), one pattern with higher intake of unprocessed F&Vs in all phytonutrient categories (High Unprocessed), one pattern with high intake of ultra-processed F&Vs (High Ultra-Processed), and one pattern with generally moderate intake of processed F&V in all phytonutrient categories (Moderate Processed). Subtle differences were noted between NHANES III and Continuous NHANES Cycles in these patterns with unprocessed F&Vs and ultra-processed F&Vs more common in some patterns (Fig. 1). To evaluate if these differences

Table 1. Weighted Characteristics and Average Dietary Intake of CKD Vs. Non-CKD Participants Across Cohorts

Variables (Mean ± SD or %)	NHANES III			Cycles 2003-2010			Cycles 2011-2018		
	CKD	Non-CKD	*P*-Value*	CKD	Non-CKD	*P*-Value*	CKD	Non-CKD	*P*-Value*
Demographics									
Age	58.5 ± 19.5	41.0 ± 15.4	<0.0001	60.3 ± 18.6	43.4 ± 16.0	<0.0001	60.0 ± 18.0	44.6 ± 17.0	<0.0001
Female sex	60.5	50.7	<0.0001	57.6	51.0	<0.0001	57.0	50.5	0.0001
Race/ethnicity			0.007			<0.0001			<0.0001
Non-Hispanic White	75.4	76.5		72.0	71.0		67.1	64.0	
Non-Hispanic	13.3	10.3		12.5	10.8		12.5	10.7	
African American									
Mexican-American	4.0	5.4		6.6	8.6		7.4	9.5	
Other	7.3	7.8		9.0	9.5		12.8	15.6	
Medical history									
Hypertension	47.5	19.6	<0.0001	56.2	25.3	<0.0001	59.7	27.1	<0.0001
Diabetes	17.3	3.6	<0.0001	26.7	6.4	<0.0001	30.4	9.2	<0.0001
Body mass index (kg/m^2)	27.6 ± 6.3	26.3 ± 5.5	<0.0001	29.4 ± 7.2	28.3 ± 6.4	<0.0001	30.5 ± 7.5	29.0 ± 7.0	<0.0001
Underweight	2.2	1.4		1.6	1.0		1.3	0.9	
Normal weight	34.2	45.3		27.1	32.7		22.0	29.4	
Overweight	33.2	32.1		30.7	33.7		29.3	32.7	
Obese	30.3	21.2		40.4	32.5		47.2	37.0	
Waist circumference (cm)	96.4 ± 15.2	91.0 ± 14.2	<0.0001	101.5 ± 16.5	97.0 ± 16.7		104.3 ± 17.2	99.0 ± 16.2	<0.0001
Male	101.0 ± 13.0	94.2 ± 13.0		106.8 ± 15.7	100.0 ± 15.0		108.4 ± 15.7	101.0 ± 14.8	
Female	93.4 ± 16.0	87.4 ± 15.0		97.5 ± 16.0	94.8 ± 16.0		101.1 ± 16.2	97.0 ± 16.0	
eGFR ($ml/min/1.73\ m^2$)	77.4 ± 40.0	111.2 ± 39.5	<0.0001	72.0 ± 28.2	99.0 ± 18.7		73.6.0 ± 29.4	98.6 ± 19.0	<0.0001
Macronutrients									
Energy (kcal)†	1647 [1226, 2219]	2080 [1524, 2840]	<0.0001	1710 [1332, 2223]	2030 [1559, 2654]	<0.0001	1782 [1382, 2254]	2004 [1548, 2869]	<0.0001
% Calories from protein	16.0 ± 5.1	15.3 ± 4.8	<0.0001	16.1 ± 4.2	16.0 ± 4.1	0.007	16.0 ± 4.4	16.0 ± 4.7	0.242
% Calories from carbohydrates	50.6 ± 11.6	49.6 ± 11.3	0.005	49.5 ± 9.6	49.0 ± 10.0	<0.0001	48.1 ± 10.0	47.3 ± 9.8	0.004
% Calories from total fat	34.0 ± 9.5	33.7 ± 9.3	0.0062	34.0 ± 7.5	33.5 ± 7.7	0.244	35.0 ± 7.8	35.0 ± 7.7	0.535
Selected Micronutrient Densities									
Dietary fiber (g/1000 kcal)†	7.9 [5.4, 11.2]	7.0 [4.8, 9.8]	<0.0001	7.9 [5.9, 10.5]	7.1 [5.3, 9.7]	<0.0001	8.1 [6.1, 10.7]	7.8 [5.7, 10.4]	0.003
Phosphorus (mg/1000 kcal)†	613 [502, 752]	582 [483, 704]	<0.0001	644 [551, 756]	629 [538, 731]	0.0002	656 [563, 760]	654 [565,760]	0.877
Sodium (mg/1000 kcal)†	1629 [1302, 1999]	1564 [1258, 1918]	0.0007	1636 [1373, 1935]	1619 [1365, 1901]	0.192	1678 [1405, 1938]	1644 [1409, 1925]	<0.0001
Potassium (mg/1000 kcal)†	1434 [1112, 1832]	1283 [1001, 1631]	<0.0001	1380 [1121, 1671]	1264 [1003, 1541]	<0.0001	1323 [1093, 1564]	1249 [1024, 1524]	<0.0001
Carotenoids (RE or mcg/1000 kcal)†,‡	115 [47, 352]	97 [41, 271]	0.002	6133 [1380, 2901]	7154 [3364, 13573]	0.004	6126 [2935, 11804]	6676 [3157, 12731]	0.011

CKD, chronic kidney disease; eGFR, estimated glomerular filtration rate; NHANES, the National Health and Nutrition Examination Survey; SD, standard deviation.

**P*-value for comparison with non-CKD adults in each 4 years/cycles of NHANES.

†*P*-values are based on tests of log transformed data. Median [interquartile range] is presented.

‡Unit reported in NHANES III for carotenoids is based on RE and in continuous NHANES is based on mcg.

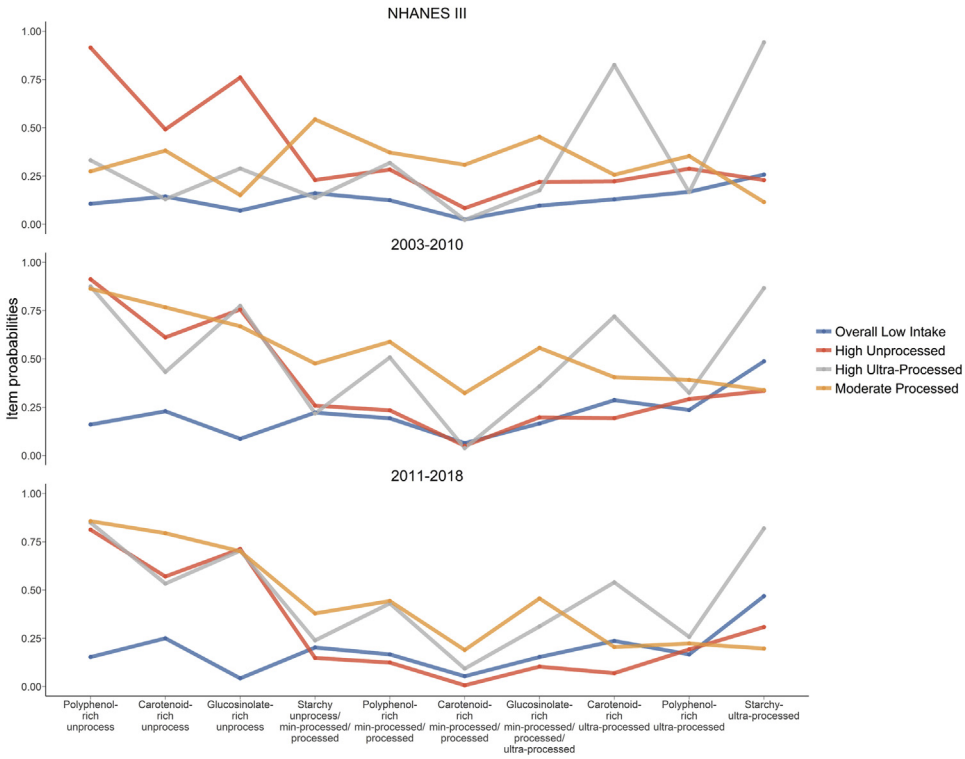

Figure 1. Probability of consumption of different fruit and vegetable (F&V) categories across patterns and cohorts. Categories of F&V foods considered in developing F&V patterns are provided along the x-axis. 12 categories were possible based on pairwise groupings of processing (unprocessed, minimally processed/processed, and ultraprocessed) and phytochemical content (glucosinolate-rich, carotenoid-rich, polyphenol-rich, and starchy). 10 categories were ultimately used in latent class analysis (LCA) because uncommon pairwise groupings consumed in <5% of participants were collapsed with adjacent groups. LCA was run separately in NHANES III and Continuous NHANES. LCA in Continuous NHANES also included a group variable for the early (2003-2010) versus late (2011-2018) period to allow patterns to qualitatively vary over time. Each of these cohorts is presented in panels from top to bottom. Colored lines within each panel depict the food patterns of the population with probabilities of consuming a food item in the indicated category on the recall day(s). These line graphs provide insight about the food categories that drive the LCA groupings and that support the descriptive labels.

may be due to secular trends or methodologic differences due to the use of 1-day (NHANES III) versus 2-day (Continuous NHANES) of 24-hour recalls, we performed LCA using only 1-day in Continuous NHANES as a sensitivity analysis. Agreement between the classifications was modest in both cycles (weighted % agreement 69 and 78%; weighted kappa 0.26 and 0.44).[25] However, with 1-day recall data we found patterns qualitatively similar to the 2-day recalls and some of the differences between NHANES III and Continuous NHANES cycles attenuated. For example, we noted less intake of unprocessed F&Vs in the Moderate Processed pattern in the 2003-2010 cycle, less intake of unprocessed F&Vs in the High Ultra-Processed pattern in the 2011-2018 cycle, and less ultra-processed F&Vs in the Overall Low Intake pattern in both Continuous cycles, each more consistent with NHANES III results (Figure S1). Thus, we concluded that the identified patterns across cycles were qualitatively similar and continued with LCA based on 2-day recalls in Continuous NHANES because they provide more data for classification.

We evaluated selected variables including total nutrient intakes and relevant clinical variables (e.g., BMI and waist circumference) across patterns to partially validate them (Table S2). As expected, in all three datasets of NHANES, dietary fiber was significantly lowest in the Overall Low Intake pattern compared to other patterns ($P < .0001$). Conversely, dietary carbohydrate and total energy was significantly highest in the High Ultra-Processed pattern compared to other patterns (both $P < .0001$). Objective biomarkers of intake demonstrated differences across patterns. We observed lower levels of many carotenoids in the Overall Low Intake and High Ultra-Processed patterns ($P < .0001$). In particular, α-carotene, β-carotene, β-cryptoxanthin, and lutein/zeaxanthin were most consistently lower in this pattern in all cycles. However, we saw higher lycopene levels in the High Ultra-Processed pattern ($P < .0001$) possibly due to the high levels of food coloring, additives, and processed tomato products used in ultra-processed foods. We also assessed levels of vitamins A, E, and C across patterns. These vitamins were typically higher in the Moderate Processed pattern (Table 2).

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Table 2. Average Levels of Serum Carotenoids, Vitamins A, E, and C as Objective Biomarkers of F&V Intake Across F&V Patterns

Variables (Mean ± SD)	Overall Low Intake	High Unprocessed	High Ultra-Processed	Moderate Processed	*P*-Value†
NHANES III					
α-Carotene (μg/dL)*	2.7 [0.9, 4.7]	3.9 [2.2, 6.4]	2.2 [0.7, 4]	4.4 [2.6, 7.2]	<0.0001
β-Carotene (μg/dL)*	12.3 [7.3, 20.6]	16.3 [9.8, 27.4]	10.7 [6.6, 17.7]	19.4 [11.1, 30]	<0.0001
β-Cryptoxanthin (μg/dL)*	6.2 [4.3, 9.7]	7.8 [5.2, 12.1]	6.1 [4.3, 8.8]	8.4 [5.4, 12.3]	<0.0001
Lycopene (μg/dL)*	21.3 [14.3, 29.2]	21.9 [15.1, 29.7]	26.7 [18.4, 34.7]	19.1 [13, 28.2]	<0.0001
Lutein/Zeaxanthin (μg/dL)	20.3 ± 11.3	23.7 ± 12.6	18.1 ± 8.4	24.8 ± 12.0	
Vitamin A (μg/dL)*	55.5 [46, 66.1]	57.9 [48.4, 69]	54.5 [45.4, 64.4]	59 [48.2, 69.6]	<0.0001
Vitamin E (μg/dL)*	1003.1 [823.4, 1250.8]	1099.1 [886.3, 1386.8]	925.9 [782.2, 1139.1]	1115.9 [912.5, 1456]	<0.0001
Vitamin C (mg/dL)*	0.6 [0.3, 1]	0.9 [0.6, 1.1]	0.6 [0.3, 0.9]	0.8 [0.5, 1.1]	<0.0001
Continuous					
NHANES 2003-2004					
α-Carotene (μg/dL)*	1.7 [0.9, 3.3]	3.0 [1.6, 5.1]	1.9 [1.2, 4]	4.3 [2.3, 7.4]	<0.0001
β-Carotene (μg/dL)*	9.0 [5.7, 15.6]	13.5 [8.0, 23.8]	10.2 [6.6, 17.8]	19.7 [10.5, 30.7]	<0.0001
β-Cryptoxanthin (μg/dL)*	5.6 [3.9, 8.4]	7.4 [4.6, 10.9]	6.8 [4.4, 10.5]	8.8 [5.4, 12.8]	<0.0001
Lycopene (μg/dL)	42.0 ± 20.0	41.3 ± 19.1	46.6 ± 19.0	40.8 ± 19.7	<0.0001
Lutein/Zeaxanthin (μg/dL)*	12.5 [9.3, 16.4]	15.1 [11.2, 19.5]	13.9 [10.4, 18.6]	16 [12.0, 21.9]	<0.0001
Vitamin A (μg/dL)	58.3 ± 16.0	60.1 ± 16.5	60.0 ± 15.8	62.3 ± 16.7	<0.0001
Vitamin E (μg/dL)*	1107.8 [886.9, 1395.1]	1235.5 [981.1, 1632.9]	1184.7 [923.3, 1595.7]	1441.2 [1078.0, 1955.1]	<0.0001
Vitamin C (mg/dL)	0.8 ± 0.5	1.0 ± 0.5	1.0 ± 0.5	1.2 ± 0.5	<0.0001
Continuous					
NHANES 2005-2006					
α-Carotene (μg/dL)*	2.0 [1.0, 3.9]	3.3 [1.8, 6.6]	2.5 [1.3, 5.2]	4.5 [2.5, 8.6]	<0.0001
β-Carotene (μg/dL)*	10.1 [6.1, 18.4]	14.3 [8.3, 27]	12.2 [7.1, 19.9]	22.9 [12, 40.2]	<0.0001
β-Cryptoxanthin (μg/dL)*	6.6 [4.2, 9.9]	8.6 [5.3, 13.3]	7.3 [4.6, 11.7]	9.8 [6.4, 15.8]	<0.0001
Lycopene (μg/dL)	43.9 ± 21.3	45.2 ± 19.7	50.0 ± 20.4	43.5 ± 18.7	<0.0001
Lutein/Zeaxanthin (μg/dL)*	12.5 [9.1, 17.7]	15.7 [10.9, 22.2]	14.6 [10, 20.1]	18 [12.7, 23.8]	<0.0001
Vitamin A (μg/dL)	60.0 ± 16.6	60.1 ± 16.7	61.7 ± 16.8	62.7 ± 16.6	<0.0001
Vitamin E (μg/dL)*	1065.5 [871.7, 1340.3]	1176.3 [962.7, 1468.6]	1166.9 [907.6, 1496.4]	1313.1 [1023, 1645.4]	<0.0001
Vitamin C (mg/dL)	0.8 ± 0.4	1.0 ± 0.4	1.0 ± 0.4	1.1 ± 0.4	<0.0001

NHANES, the National Health and Nutrition Examination Survey; SD, standard deviation.
*Log transformed prior to testing and reported as Median [interquartile range].
†*P*-value for global comparison across patterns using ANOVA.

Association of CKD with Patterns of Fruit and Vegetable Intake

In all cycles and groups the most common pattern was Overall Low Intake. In unadjusted analysis this pattern was less common in CKD (Fig. 2A). After adjusting for demographics, waist circumference, diabetes, and hypertension using multinomial logistic regression (Table S3), participants with CKD were more likely to be classified in the Overall Low Intake pattern (Figure 2B). The overall association of CKD with F&V patterns was significant in NHANES III ($P = .05$) and Continuous NHANES 2003-2010 ($P = .005$), but not in Continuous NHANES 2011-2018 ($P = .4$) based on the model F-test. Models only adjusting for demographic variables yielded similar results (data not shown). Sensitivity analyses using the 1-step modeling approach were also similar (Table S4).

Discussion

In this study, we characterized patterns of F&V intake in nationally representative samples of the US population and compared the patterns of intake in individuals with and without CKD. LCA classified F&V consumption into 4 broad patterns. We showed that in NHANES III and Continuous NHANES 2003-2010, participants with CKD were more likely to consume patterns with low consumption of different F&Vs compared to similar participants without CKD. A similar direction of association was noted in Continuous NHANES 2011-2018, but it was not statistically significant, perhaps because more individuals with CKD in this cycle were in earlier stages of CKD with albuminuria alone. It is important to acknowledge that these data are cross-sectional. These associations may suggest that low intake of F&Vs is a risk factor for development of CKD. Alternatively, this could reflect lower intake

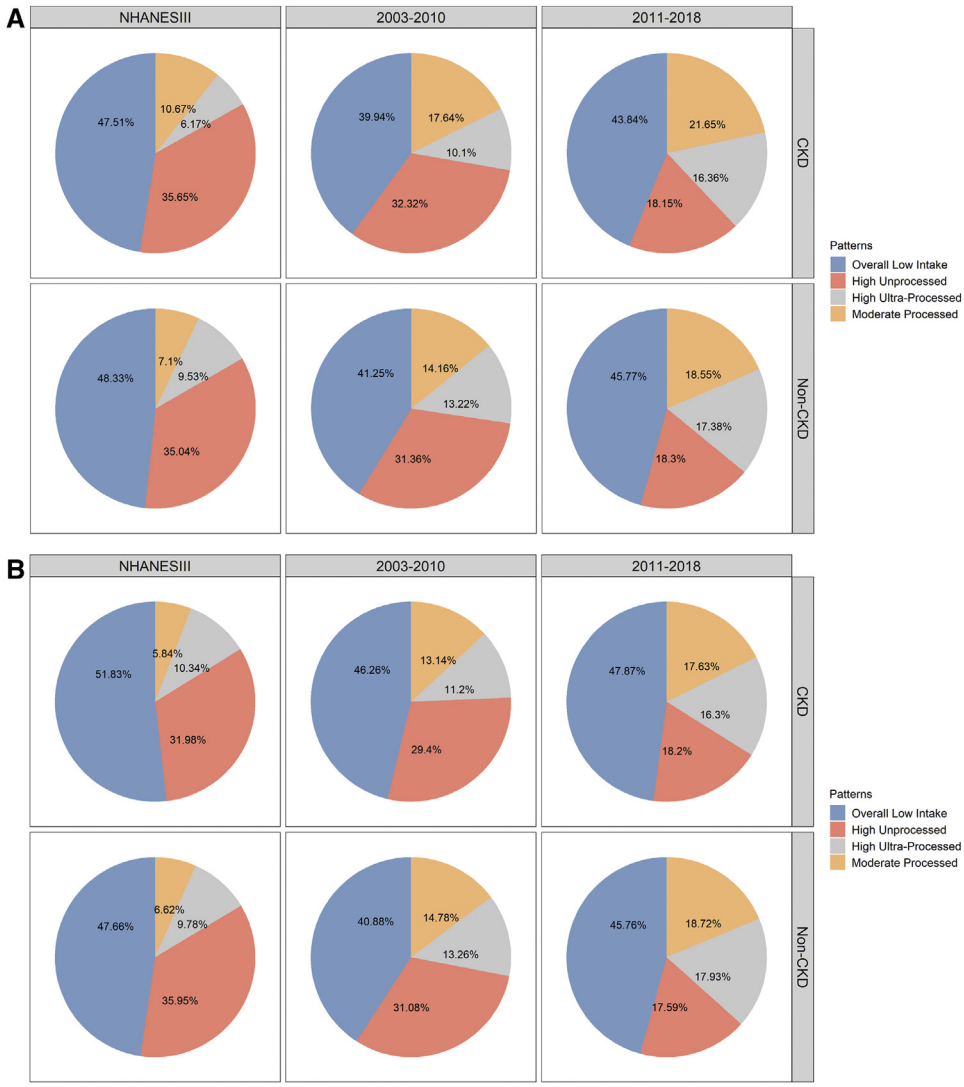

Figure 2. Probabilities of membership in each fruit and vegetable (F&V) pattern comparing CKD and non-CKD groups. Probabilities are presented: A) Unadjusted; and, B) As marginal predicted probabilities adjusted for gender, race, age, waist circumference, diabetes (yes/no), and hypertension (yes/no). Marginal probabilities are derived from a multinomial logistic regression model. Model-based probabilities are calculated for the full weighted population as if all had CKD compared to calculated probabilities if all did not have CKD. Other covariates in the model are assigned their observed level. *P*-values represent global F-test of the multinomial logistic regression model.

of F&Vs among individuals with CKD because of the common advice to reduce potassium intake, often via reduced F&Vs. Distinguishing these possibilities will require longitudinal studies evaluating the association of F&V patterns with new onset CKD or CKD progression.

Participants in all cycles and CKD groups were most commonly classified into the Overall Low Intake pattern of F&Vs. This provides more evidence of generally low consumption of F&Vs in the US population.[26,27] We also assessed F&V patterns across NHANES cycles to evaluate qualitative differences in patterns. We found that F&V patterns were generally stable over the time period examined. Although there were some subtle differences between NHANES III and the Continuous NHANES cycles, these were not robust when we used only 1 day of dietary intake to define them. Therefore, we interpret these subtle differences as primarily due to methodologic differences, as opposed to true time trends. Our finding of relatively stable patterns is consistent with previous studies, in which other dietary pattern classification has also remained mostly stable over time.[28,29]

On first glance the micronutrient differences between CKD and non-CKD groups do not seem to support the assertion that F&Vs may be avoided to reduce dietary potassium. In fact, patients with CKD had higher dietary potassium density than non-CKD participants. Nutrient densities reflect the amount of the nutrient indexed to a specific calorie level, in this case per 1000 kcal per day.

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Patients with CKD consumed fewer overall calories; therefore, their total potassium intake may be lower, but there were other changes in the food matrix that lowered calories by even more. Also, it is important to note that these results were from unadjusted analyses. In the unadjusted pattern analysis, CKD participants also had a lower prevalence of the Overall Low Intake pattern. After adjustment, the result shifted direction. We believe these differences are due to the substantially different age distributions in the CKD versus non-CKD participants. When accounting for age, differences in micronutrient intakes may also change. Additionally, micronutrients, such as potassium, are not restricted to F&Vs. Meat and processed foods can be a major source of dietary potassium, sodium, and phosphorus.[30] Our analyses attempt to move the field away from an overly reductionist view of isolated nutrients and toward evaluation of foods, such as F&Vs.

Our approach was novel but also has some limitations. We recognize the relatively modest classification diagnostics observed in our study. This is not surprising given the low precision with which habitual diet is measured by a single day, or even 2 days, of dietary recall information. Furthermore, classification of individual foods into categories can be subjective and nutrient content may also depend on factors such as freshness or growing conditions. We used expert consensus and available literature to decide which F&Vs are rich in carotenoids, polyphenols, or glucosinolates. Our approach is consistent with others as phytochemical content of F&V typically correlate with their color.[19,20,31] Classification of processing was also at times limited by the availability of information. Foods in which inadequate information was available to determine processing status was assumed to be minimally processed or processed, which may be incorrect. Finally, we were unable to classify F&Vs that may have been consumed in mixed dishes which could lead to some misclassification. Despite these limitations, we observed differences in objective biomarkers of F&V intake, such as serum carotenoids across patterns, suggesting real differences in habitual intake. We also obtained similar results for the association with CKD using a 1-step modeling approach that retained the imprecision of classification in the final modeling step, suggesting a more robust result. Future studies can build off this initial work using more detailed dietary collections, such as more days of dietary recall interviews, food records, or food frequency questionnaires. Our analyses focus exclusively on F&V foods. We did not evaluate other aspects of the dietary pattern, such as protein-rich foods or grains. Furthermore, the overall processing of all foods in the diet was not characterized in the LCA, but only the processing of F&V foods.

To our knowledge, this study is novel in its interest in patterns of F&V intake in the US population and in patients with CKD, with a focus on their phytochemical content and processing. Most of the current research on dietary intake in CKD has focused on single nutrients (e.g., sodium, potassium, phosphorus, and protein) or single foods. Dietary pattern is a complex phenotype. It is important to consider the interaction of nutrients in foods rather than isolating nutrients or restricting them in the diet. Understanding patterns of F&V intake among CKD patients may provide a perspective different than traditional restrictive dietary guidelines.

Practical Application

In this study, participants with CKD consumed patterns of F&V characterized by lower overall intake. This study is a first step to identify F&V patterns that associate with CKD and supports the need for implementation studies to encourage higher consumption of F&Vs in the overall population as well as patients with CKD. Longitudinal follow-up studies are needed to examine the association of different patterns of F&V intake with CKD outcomes.

Credit Authorship Contribution Statement

Shirin Pourafshar: Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing, approved the final manuscript. **Binu Sharma:** Data curation, Formal analysis, Methodology, Visualization, Writing – review & editing, approved the final manuscript. **Sibylle Kranz:** Conceptualization, Supervision, Writing – review & editing, approved the final manuscript. **Indika Mallawaarachchi:** Methodology, Writing – review & editing, approved the final manuscript. **Elizabeth Kurland:** Project administration, Writing – review & editing, approved the final manuscript. **Jennie Z. Ma:** Methodology, Supervision, Writing – review & editing, approved the final manuscript. **Julia J. Scialla:** Conceptualization, Supervision, Writing – original draft, Writing – review & editing, approved the final manuscript.

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Supplementary Data

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1053/j.jrn.2022.06.007.

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