Pediatric Nephrology (2022) 37:1657–1665
https://doi.org/10.1007/s00467-021-05365-5

ORIGINAL ARTICLE

Potassium and fiber: a controversial couple in the nutritional management of children with chronic kidney disease

Amina El Amouri[1] · Kato Delva[2] · Aurélie Foulon[2] · Charlotte Vande Moortel[2] · Koen Van Hoeck[3] · Griet Glorieux[2] · Wim Van Biesen[2] · Johan Vande Walle[1] · Ann Raes[1] · Evelien Snauwaert[1] · Sunny Eloot[2]

Received: 22 June 2021 / Revised: 26 October 2021 / Accepted: 9 November 2021 / Published online: 7 January 2022

Abstract

Background Fruit and vegetable intake is commonly discouraged in children with chronic kidney disease (CKD) to avoid hyperkalemia. However, direct evidence in support of this widespread practice is lacking. Furthermore, the resultant restricted fiber exposure may deprive CKD patients from potential health benefits associated with the latter. Therefore, we investigated associations between dietary potassium intake, fiber intake, and serum potassium levels in pediatric CKD.

Methods This study is a longitudinal analysis of a 2-year, prospective, multi-institutional study, following children with CKD at 3-month intervals. At each visit, dietary potassium and fiber intake were assessed, using 24-h recalls and 3-day food records. On the same occasion, serum potassium concentrations were determined. Associations between dietary potassium intake, dietary fiber intake, and serum potassium concentrations were determined using linear mixed models.

Results Fifty-two CKD patients (7 transplant recipients, none on dialysis) aged 9 [4;14] years with an estimated glomerular filtration rate (eGFR) of 49 [25;68] mL/min/1.73 m^2 were included. For every g/day decrease in dietary potassium intake, the estimated mean daily fiber intake was 5.1 g lower (95% confidence interval (CI), 4.3–5.9 g/day; $p < 0.001$). Neither dietary potassium intake ($p = 0.40$) nor dietary fiber intake ($p = 0.43$) was associated with circulating potassium in a model adjusted for time point, eGFR, treatment with a renin–angiotensin–aldosterone system blocker, serum bicarbonate concentration, and body surface area.

Conclusions Dietary potassium and fiber intake are closely related but were not associated with circulating potassium levels in pediatric CKD.

Keywords Chronic kidney disease · Pediatric · Diet · Fiber intake · Potassium intake · Serum potassium

Introduction

Strict dietary potassium restriction is recommended by many nephrology teams in children with chronic kidney disease (CKD) with or out of assumed risk of hyperkalemia [1]. Nevertheless, robust data underpinning the risk of hyperkalemia of the desired ranges are lacking, and the psycho-social impact of such dietary restrictions on the child and the family is seldom highlighted [2, 3]. In addition, there are no data regarding the extent of dietary potassium restriction needed to prevent or treat hyperkalemia [1]. While randomized trials are lacking, several observational studies report no or poor associations between dietary potassium intake estimations and serum potassium levels or rates of hyperkalemia in adults with CKD [4–9]. In fact, there is only limited, low-quality evidence supporting the claim that a low-potassium diet

Ann Raes, Evelien Snauwaert and Sunny Eloot contributed equally to this work.

✉ Amina El Amouri
amina.elamouri@ugent.be

[1] Pediatric Nephrology and Rheumatology, ERKNet Center, Ghent University Hospital, Corneel Heymanslaan 10, 9000 Ghent, Belgium

[2] Nephrology, Ghent University Hospital, Corneel Heymanslaan 10, 9000 Ghent, Belgium

[3] Pediatric Nephrology, Antwerp University Hospital, Wilrijkstraat 10, 2650 Edegem, Antwerp, Belgium

actually reduces serum potassium levels [4]. To date, the relationship between dietary potassium intake and serum potassium levels in pediatric CKD is unexplored.

In addition, an important undesirable side-effect of limiting potassium intake through avoidance of fruit and vegetable consumption is the lower fiber exposure. In adult CKD patients, higher fiber intake has been linked to a positive effect on uremia-associated gut dysbiosis, improved metabolic acidosis, better lipid profiles, lower cardiovascular disease risk, lower risk of inflammation, and reduced mortality [10–12]. In parallel, the study of plant-based dietary patterns in adult CKD gained popularity, since a growing body of evidence indicates potential benefits in cardiovascular and mortality outcomes. Plant-based dietary patterns characteristically consist of fruits, vegetables, legumes, whole grains, nuts and seeds, thus being rich in both potassium and fiber [11, 13–16]. It remains unclear whether these benefits are attributable to potassium intake per se, a higher associated intake of vitamins, anti-oxidants and fiber, or an overall healthier lifestyle [11].

The aim of this study was to investigate associations between dietary potassium or fiber intake and serum potassium levels across different stages of pediatric CKD and to examine whether potassium and fiber intake correlate.

Methods

Study design and population

This study analyzes observational, longitudinal data from the 2-year, prospective, multicenter UToPaed study (NCT02624466), running from September 2015 to March 2019. Patients were children aged < 18 years, with a confirmed CKD diagnosis stage 1–5 (defined using the Kidney Disease Improving Global Outcomes (KDIGO) guidelines), including kidney transplant recipients. Estimated glomerular filtration rate (eGFR), calculated by the updated Schwartz equation [17], was used to define CKD strata. Children undergoing dialysis were excluded. Assessments were made during a stable disease status; children with active infection or inflammatory disease and malignancies were excluded. The 52 eligible patients who had available concurrent serum potassium measurements and assessments of dietary potassium and fiber intakes in the present cohort were recruited from the Departments of Pediatric Nephrology of Ghent University Hospital and Antwerp University Hospital. The study flow chart is depicted in Fig. 1. The study protocol was approved by the Ethics Committee of both centers (B670201524922). Written informed consent or assent was obtained from all legal guardians or participants above the age of 12, respectively.

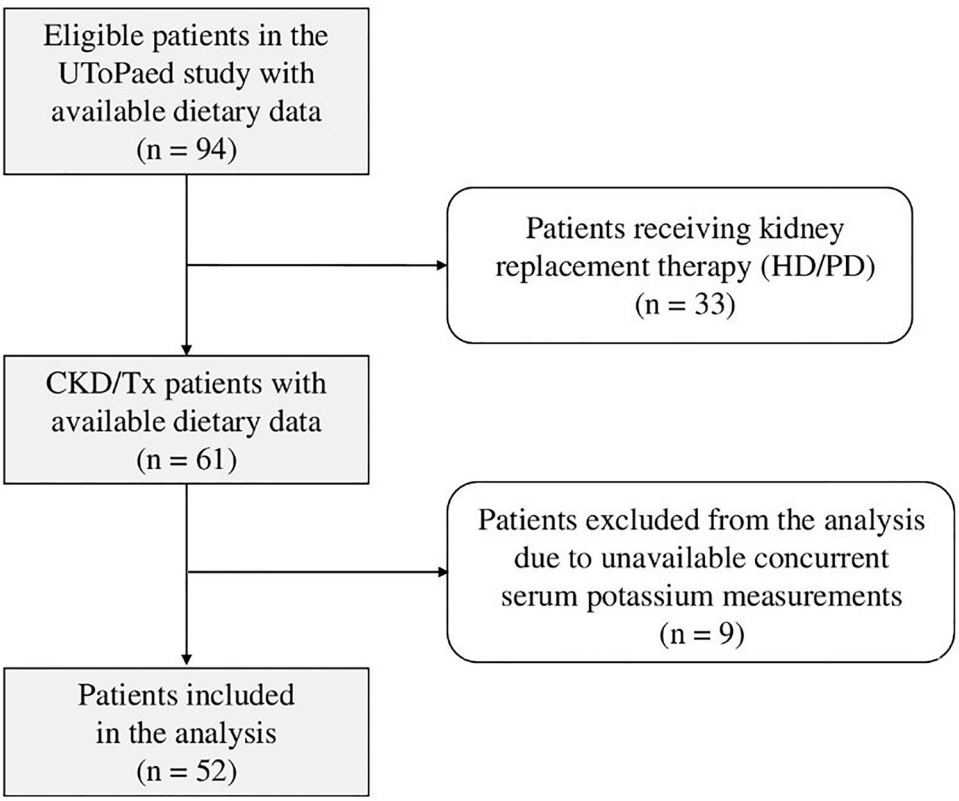

Fig. 1 Study flow chart

Study variables and biochemical assessments

Data of interest for this analysis, collected at baseline and prospectively every trimestral visit, included demographics, cause of CKD, history of kidney transplant, anthropometric data for nutritional status assessment (standard deviation scores (SDS) for height, weight and body mass index (BMI)), medications, laboratory data, and diet histories (as detailed below).

Blood samples were collected from all patients as part of the routine clinical examination. Serum creatinine (photometric method), bicarbonate (photometric method), and potassium (indirect potentiometric method) concentrations were analyzed by the respective Clinical Laboratories of the University hospitals of Ghent and Antwerp.

Dietary assessment

Detailed diet histories were obtained using a 3-day food record or a 24-h dietary recall at an aimed 50:50 ratio across the total follow-up period. For the 3-day food record, patients and/or their caregivers were asked to complete a printed, structured diary that was subsequently verified by the dietician in a face-to-face interview. Twenty-four-hour recalls comprised a detailed recollection of everything the patient consumed (foods, beverages, sauces, condiments, dietary supplements) the day prior to the consultation and were completed directly by the dietician. If for some reason patients forgot to fill out or bring the 3-day food record for the visit, a 24-h recall was carried out instead so that dietary data could be matched to laboratory data. Standardized food models, a color photo atlas with choice between varying portion sizes and their corresponding weight of different food groups (Portiegroottes boek, Valetudo Consulting, third edition, March 2014), and a manual for the conversion of household measures to weight equivalents and standardized quantification of food items were used to increase accuracy of serving size estimations [18]. Non-standard mixed meals and recipes were broken down into their constituents. Subsequently, food records were entered into Evry-Diëtist 6.7.7.0 (Evry BV, Alphen aan den Rijn, The Netherlands), according to the Belgian Branded Food Products Database (Nubel, 5th Edition). Alternatively, unknown food items were searched in the Dutch nutrient database (Nevo, 4th Edition) or in the online database of trade names (Internubel). In case nutritional information was unavailable, manufacturers' labels or online sites of the branded foods were used. Total energy, potassium, and fiber intake for every child was computed as the sum of all food items. All participants in our study received standard dietary counselling by a renal dietician. Dietary potassium restrictions were only implemented when clinically meaningful, repetitive hyperkalemia occurred.

Estimated daily potassium intake was expressed in mg/day and standardized to mg per kg body weight to compare to age-dependent National Kidney Foundation Kidney Disease Outcomes Quality Initiative (KDOQI) guidelines to prevent and treat hyperkalemia. Fiber, expressed in g/day, was corrected for body surface area (BSA), calculated by the Haycock formula ($BSA = 0.024265 \times (length^{0.3964}) \times (weight^{0.5378})$ m^2). Finally, the percentage dietary reference intake (%DRI) was calculated, expressing total dietary fiber intake as a percentage of the age-dependent DRI for fiber, according to the Belgian nutrition recommendation for healthy children [19].

Statistical analyses

Normality of distributions was assessed by the Shapiro–Wilk test. Continuous variables are expressed as mean ± standard deviation (SD) or median [25th;75th percentile], as appropriate. Categorical variables are reported as frequencies and proportions. To compare potassium intake between the CKD stages, a Kruskal–Wallis test with post hoc Dunn's analysis and Bonferroni correction was used to account for multiple testing. Fiber intake was compared between the CKD stages by a one-way ANOVA test with post hoc Tukey comparison. In order to examine the correlation between dietary fiber intake and potassium intake, a simple linear mixed model for daily fiber intake was fitted with a random intercept for patient and with daily potassium intake as the only explanatory variable in the fixed effects part of the model. The proportional reduction in within-subject variance and between-subject variance (compared to a null model) was computed as analogue to R^2 for multilevel data. Linear mixed models for serum potassium concentration were fitted with a random intercept for patient, to take into account the repeated measurements within patients over time. The fixed effects part of a first model contained the main effects of dietary intake (g/day) and time point (categorical 0, 3, 6, 9, 12, 15, 18, 21, and 24 months). A second model was further adjusted for eGFR (ml/min/1.73 m^2), treatment with a renin–angiotensin–aldosterone system (RAAS) blocker (yes/no), metabolic acidosis represented by serum bicarbonate concentration (mEq/L), and body surface area (m^2) as a proxy for age. All hypothesis testings were performed at the two-sided 5% significance level. All statistical analyses were performed using SPSS 26.0 (IBM, New York, USA), while the graphics were made in R version 3.6.1. Statistical analyses were conducted by the Biostatistics Unit of Ghent University.

Results

Data from 52 children with CKD 1–5, of which 7 kidney transplant recipients, were analyzed. This accounted for a total of 279 repeated patient visits with a mean of 5 visits

(range 1–9) per patient and a median follow-up time of 19 [14;23] months. Baseline demographic, clinical, laboratory and dietary characteristics by eGFR category are presented in Table 1. Our cohort were mainly boys with a median age of 9 [4;14] years and an eGFR of 49 [25;68] mL/min/1.73 m^2. Metabolic acidosis, defined as serum bicarbonate < 22 mEq/L, was present in 23/51 (45%) patients. Of the 20 patients treated with RAAS inhibitors, only one was on an angiotensin receptor blocker. One patient took a loop diuretic (furosemide) in addition to an angiotensin-converting enzyme inhibitor, while none of the patients were on potassium sparing diuretics. Potassium and fiber intakes were estimated by 3-day food records/24-h recalls in a 40/60 ratio in comparison to the intended 50/50 ratio.

As summarized in Table 1, the median dietary potassium intake was 62 [44;81] mg/kg/day. In children aged 1–5 years, the median potassium intake of 76 [54;135] falls within the potassium-restricted diet range of 40–120 mg/kg/day provided by the KDOQI guidelines as a starting point for infants and young children (Supplementary Table 1). The vague KDOQI guideline does not allow a similar comparison for older children. The %DRI for fiber varies between CKD stages ($p = 0.007$), with a lower fiber intake in patients with CKD stages 4–5 versus stages 1–2 ($p = 0.005$).

A simple linear mixed model for daily fiber intake with daily potassium intake as the only explanatory variable revealed that for a daily potassium intake decrease of 1 g, the estimated mean daily fiber intake decreased by 5.1 g (95% confidence interval (CI), 4.3 to 5.9 g/day; $p < 0.001$). The within-subject variance in daily fiber intake could be explained for 28% by the daily potassium intake. The between-subject variance in daily fiber intake could be explained for 65% by the daily potassium intake (Fig. 2).

Linear mixed model analysis revealed no association between dietary potassium intake (g/day) and serum potassium concentration in a model adjusted for time point

Table 1 Baseline demographic, clinical, laboratory, and dietary characteristics across different stages of CKD

Variables	Overall	CKD 1–2	CKD 3	CKD 4–5
Number of patients (n)	52	18	17	17
Demographics				
Age (years)	8.6 (4.4–14.2)	8.6 (4.9–9.2)	11.9 (7.3–14.7)	7.8 (3.0–13.8)
Male sex	38 (73)	11 (61)	14 (82)	13 (77)
Anthropometrics				
Weight SDS	– 1.0 ± 1.4	– 0.9 ± 1.2	– 1.2 ± 1.8	– 0.9 ± 1.0
Height SDS	– 1.2 ± 1.2	– 1.2 ± 1.2	– 1.1 ± 1.4	– 1.4 ± 0.9
BMI SDS	– 0.3 ± 1.2	– 1.8 ± 0.9	– 0.7 ± 1.5	– 0.1 ± 1.2
Cause of CKD				
Glomerular	8 (15)	4 (22)	3 (18)	1 (6)
CAKUT	25 (48)	5 (28)	8 (47)	12 (71)
Cystic disease	4 (8)	1 (6)	2 (12)	1 (6)
Other non-glomerular	15 (29)	8 (44)	4 (24)	3 (18)
Medication				
RAAS blockers	20 (39)	7 (39)	6 (35)	7 (41)
Sodium bicarbonate	18 (35)*	3 (17)	4 (24)	11 (65)
Potassium binding resin	7 (14)	0 (0)	3 (18)	4 (24)
Laboratory parameters				
eGFR (mL/min/1.73 m^2)	48.5 (25.2–68.2)	73.4 (65.9–100)	45.9 (36.2–54.4)	18.5 (13.7–25.5)
Serum potassium (mEq/L)	4.6 ± 0.6	4.4 ± 0.5	4.8 ± 0.6	4.7 ± 0.5
Serum bicarbonate (mEq/L)	22.4 ± 3.0	22.0 ± 3.5	23.0 ± 2.5	22.2 ± 3.0
Dietary intake				
Potassium intake (g/day)	1.71 ± 0.812	1.97 ± 0. 874	1.94 ± 0.814	1.27 ± 0.657
Potassium intake (mg/kg/day)	61.8 (43.5–81.4)	76.6 (64.5 –114)	67.9 (38.0–83.0)	50.2 (41.4–59.4)
Fiber intake (g/day)	11.9 ± 6.4	13.4 ± 6.0	13.5 ± 6.1	8.7 ± 6.2
Fiber/BSA (g/m^2/day)	11.1 (7.8 –16.1)	16.0 (12.4–20.4)	10.1 (7.7–13.3)	8.8 (4.0–12.0)
%DRI fiber	75.2 ± 38.3	92.1 ± 37.3	79.3 ± 33.8	53.0 ± 34.6

Data are expressed as mean ± standard deviation (SD), number (percentage), or median (25th–75th percentile) as appropriate. *SDS*, standard deviation score; *BMI*, body mass index; *CAKUT*, congenital abnormalities of the kidney and urinary tract; *RAAS*, renin–angiotensin–aldosterone system; *eGFR*, estimated glomerular filtration rate; *BSA*, body surface area, *DRI*, dietary reference intake. *$n = 51$; missing data from one patient

($p = 0.34$), nor in a model adjusted for time point, eGFR, treatment with RAAS-inhibitor therapy, serum bicarbonate concentration, and body surface area ($p = 0.40$). Neither could an association be found between dietary fiber intake (g/day) and serum potassium concentration, using the same two models (Table 2).

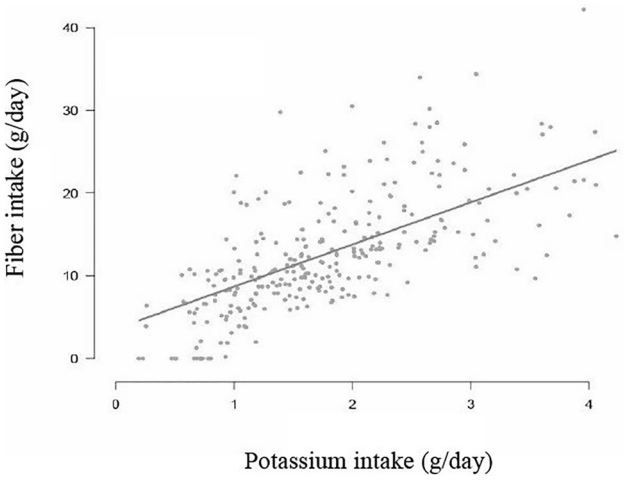

Fig. 2 Scatter plot of the correlation between dietary fiber and potassium intake

Discussion

This study is the first to investigate the link between dietary potassium and fiber intake and serum potassium levels across different stages of CKD in a pediatric population. The key findings are (i) dietary potassium intake correlates with dietary fiber intake and (ii) there is no association between the estimated amount of dietary potassium consumed nor dietary fiber intake and circulating potassium in these patients.

First, we observed that every g/day decrease in dietary potassium intake was associated with an approximate fivefold decrease in dietary fiber. The present association between dietary potassium intake and fiber intake gives strength to our hypothesis that excessive restrictions in high-potassium foods, which are part of the intensification of nutritional counselling as CKD advances play an important role in limiting fiber intake. Fiber sources are exclusively plant-based and often have a high potassium content.

Table 2 Linear mixed model analysis of serum potassium concentration

Parameters	Estimate	95% confidence interval		*P*
		Upper bound	Lower bound	
Dietary potassium				
Model 1				
Dietary potassium (g/day)	0.034	– 0.036	0.10	0.34
Model 2				
Dietary potassium (g/day)	0.030	– 0.040	0.10	0.40
eGFR	– 0.0025	– 0.0056	– 0.00055	0.11
RAAS blocker use	– 0.17	– 0.34	0.0028	0.05
Serum bicarbonate (mEq/L)	– 0.026	– 0.048	– 0.0038	0.02
BSA (m^2)	0.20	– 0.040	0.44	0.10
Dietary fiber				
Model 1				
Dietary fiber (g/day)	0.0039	– 0.0044	0.012	0.36
Model 2				
Dietary fiber (g/day)	0.0033	– 0.0050	0.012	0.43
eGFR	– 0.0024	– 0.0054	0.00060	0.12
RAAS blocker use	– 0.17	– 0.34	0.0035	0.06
Serum bicarbonate (mEq/L)	– 0.026	– 0.048	– 0.0044	0.02
BSA (m^2)	0.20	– 0.039	0.44	0.10

Model 1: adjusted for time point

Model 2: adjusted for time point, dietary fiber or dietary potassium, eGFR, RAAS blocker use, serum bicarbonate, and BSA

The estimate can be interpreted as the estimated mean change in serum potassium concentration for each unit increase in the explanatory variable

eGFR, estimated glomerular filtration rate; *RAAS*, renin–angiotensin–aldosterone system; *BSA*, body surface area (as a proxy for age)

As such, the consumption of vegetables and fruits is often a target of potassium restriction. However, there is a large spectrum of potassium content per unit of fiber in plant foods [20, 21]. Also, there are numerous non-plant based dietary potassium sources, containing little to no fiber at all (e.g., foods of animal-origin, fast foods, beverages, sugar and sweets). Intriguingly, the top 3 contributors of potassium in adults on hemodialysis (HD) were meat products (beef, chicken, and 'Mexican food') [5]. Vegetables do not even appear in the reported top 3 of major dietary potassium sources in childhood CKD, namely milk, fruit (of which the contributory proportion diminished as age advanced), and fast foods [22]. Similarly, we observed an overall low fruit and vegetable intake in our cohort, in which fruits and vegetables had a median contribution of 34% [14;50] to the calculated potassium intake (data not shown). Of note, potato was the single largest contributor in the fruit/vegetable group and after the exclusion of potato and banana, the contribution further dropped to 16% [12;33]. It is often unrecognized that meat products contain nearly as much or more potassium than many fruits and vegetables, especially when potassium additives are used in enhanced meats or processed foods, resulting in a 2- to threefold increase in potassium content [6, 23]. In addition, potassium in plant foods (50–60%) is absorbed to a lesser extent, compared to animal sources (80%) and additives (100%) [24–26].

Second, we found no association between dietary potassium intake and serum potassium, which is in line with observational studies in the adult CKD and HD population and a recent meta-analysis [5–7, 9, 27–29]. The scarce potassium balance studies in adults with CKD showing an elevation of serum potassium after receiving potassium supplements are not clinically relevant, as the reported doses of potassium supplements exceed those of a normal diet [4, 30–32]. Potassium is not ingested in isolation, but as part of a meal, in which other nutrients influence potassium distribution and excretion [6]. Plant sources have the advantage that they promote intracellular potassium deposition because of their alkaline and insulin-stimulating properties [6, 24–26, 33]. Moreover, the accompanying fiber content in plant-based foods has been described to have a protective effect on serum potassium as it improves constipation, hereby facilitating fecal potassium excretion [4]. In addition, it has been reported that several non-dietary factors (e.g., use of RAAS inhibitors, catabolism, metabolic acidosis) might be more important determinants of serum potassium and hyperkalemia, further questioning the impact of diet on serum potassium [4, 6, 11, 27]. Notwithstanding our endeavour to approximate potassium intake to the best of our ability, exact quantification of dietary potassium exposure is impossible (unless the child is exclusively on formula feeding) in this as in any other study [21]. Hidden sources (salt substitutes, additives in enhanced and processed foods which are not mentioned on food labels or changing manufacturers' recipes), lack of bioavailability data, all potentially underestimate the actual dietary potassium exposure. On the other hand, unreported cooking methods might underestimate potassium losses during food preparation and result in an overestimation [4, 13, 21]. The assessment of dietary potassium alone cannot explain the lack of association between dietary potassium and serum potassium, since adults with CKD and on HD report potassium and fiber intakes below those of non-CKD controls, as well as in children with CKD [6, 9, 34, 35]. In addition, fiber intake was not associated with serum potassium either. Nonetheless, opinion-based dietary potassium restriction is still widely recommended in CKD patients with or at risk of hyperkalemia [1, 4, 36]. Data and formal recommendations for potassium and fiber requirements in children with CKD are lacking [1, 21]. However, in a recently published clinical practice guideline, the Pediatric Renal Nutrition Taskforce advises not to modify dietary potassium intake, unless the child exhibits dyskalemia [21].

Emerging evidence in adults with CKD points to a relationship between higher consumption of plant foods, a delay in CKD progression and lower cardiovascular mortality [15, 16, 37]. Three seminal experimental trials showed that in adult patients with CKD and metabolic acidosis, increased fruit and vegetable consumption was associated with improved cardiovascular risk factors, without any repercussions on serum potassium [38–40]. Subsequently, whole-diet approaches and plant-based dietary patterns have gained popularity [41], since the traditional attempt to synchronize multiple single nutrient restrictions (phosphorous, salt, potassium) in CKD patients usually results in ambiguous and complicated nutritional messages and compromises overall diet quality [20, 42]. In adults with CKD, dietary interventions have been reported as burdensome, confusing, and constraining, mostly resulting in poor compliance. Moreover, overzealous dietary restrictions and lifestyle modifications may negatively impact on quality of life (QoL) [2, 42–44]. With the adherence and QoL of our patients in mind, we plead for a whole-diet rather than a traditional single-nutrient strategy, in the absence of established hyperkalemia. Dietary advice should be a concerted effort, marrying the expertise of the nephrologist to that of the dietician and requires a tailored approach as needs will likely differ per CKD stage, patient preferences, food literacy, socio-economic factors etc. A possible approach to safeguard fiber intake would be to map all non-dietary causes facilitating hyperkalemia, preferentially targeting foods of low nutritional quality with a high potassium content, avoidance of potassium additives, next reviewing, and educating on cooking procedures to lower potassium content (e.g., boiling and shredding) and prioritizing plant foods with a low potassium to fiber ratio [20, 21].

This study has some limitations. Inherent reporting inaccuracies of food records and dietary recalls cannot be ruled out. However, dietary recalls allow us to (partially) account for preparation methods and have a lesser recall bias compared to food frequency questionnaires [4]. Ideally, dietary assessment should be complemented by multiple 24-h urinary potassium excretion profiles, (since using a monospot is a poor surrogate due to the circadian aldosterone secretion), but this is burdensome and impractical, especially in non-potty-trained children. We report data from a single country and therefore geographic, racial, and cultural differences in eating pattern should be kept in mind. Causality assessment of these observational findings requires interventional trials. We believe that it is necessary to approach and analyze non-dialysis and dialysis populations separately in light of the great differences in potassium handling, comorbidities, frailty, and possible differing effects of dietary patterns [4, 11, 13]. Therefore, our observations need to be confirmed in children with CKD requiring HD.

The major strength of the present study includes its originality, as it is the first to demonstrate the absence of an association between dietary potassium or fiber intake and circulating potassium in pediatric patients at different stages of (non-dialysis) CKD. Repeated measurements of dietary intakes as well as serum potassium levels over a 2-year period allowed us to account for possible intra-patient variability and seasonal variation in dietary intake. In light of the scarcely available pediatric data, our findings are useful from an epidemiological point of view and provide insight into the controversial potassium management in pediatric CKD. Our observations fuel the discussion whether pre-emptive (in the absence of clinical signs or lab findings) restriction of fruits and vegetables is truly effective in preventing hyperkalemia [6]. These findings should raise awareness among clinicians and make them critically reflect whether the widely implemented potassium restriction is fully justified, since it may deprive patients of other potential health benefits of plant-based dietary patterns. They further underscore the need for and importance of interventional studies examining the effect of plant-based diets on relevant outcomes in addition to its safety and efficacy in pediatric CKD, especially in advanced stages.

In conclusion, dietary potassium and fiber intake are closely related but were not associated with serum potassium levels in pediatric non-dialysis CKD. Excessive dietary potassium restriction may deprive patients of other potential beneficial effects of plant-based dietary patterns and deserves reconsideration. Therefore, if downward adjustments of potassium intake are deemed necessary, the focus should shift from mere potassium content to potassium sources to safeguard fiber intake.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00467-021-05365-5.

Acknowledgements The authors wish to thank Sofie Vermeiren, Els Holvoet, Sophie Lobbestael, Tom Mertens, Maria Van Landschoot, An Desloovere, Sofie Eerens, Kimi Lambregts, Katrien Wellens, and Jarrik Fransen for their assistance.

Author contribution Conceptualization, A.E.A., E.S., S.E., A.R., J.V.W., G.G. and W.V.B.; methodology, A.E.A., E.S., G.G., S.E. and A.R.; formal analysis, A.E.A., K.D., A.F., C.V.M. and E.S.; investigation, A.E.A., A.F., C.V.M., E.S., K.V.H.; resources, A.R., J.V.W., K.V.H., G.G. and S.E.; data curation, E.S., A.F., C.V.M., A.E.A.; writing—original draft preparation, A.E.A.; writing—review and editing, A.E.A., K.D., E.S., S.E., A.R., J.V.W., G.G. and W.V.B.; visualization, A.E.A., E.S., A.R., G.G. and W.V.B. and S.E.; supervision, S.E.; project administration, A.R. and S.E.; funding acquisition, A.R. and S.E. All authors have read and agreed to the published version of the manuscript.

Funding The UToPaed study was funded by the Agency for Innovation by Science and Technology (IWT), from the 'Applied Biomedical Research with a Primary Societal Goal' (TBM) program in Flanders (Belgium): grant number IWT-TBM 150195. The first author is supported by a University Starting Grant issued by the Special Research Fund, project number 01N11119, Ghent University, Flanders, Belgium.

Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Code availability Not applicable.

Declarations

Ethics approval Approval was obtained from the ethics committee of Ghent University.

Consent to participate Written informed consent was obtained from the parents and children above the age of 12 years.

Consent for publication Not applicable.

Conflict of interest J.V.W. received lecture fees from Vitaflo and is member of the European Society for Pediatric Nephrology (ESPN) nutritional task force (with Vitaflo grant). The other authors have no conflicts of interest to declare.

References

1. (2009) KDOQI Clinical Practice Guideline for Nutrition in Children with CKD: 2008 update. Executive summary. Am J Kidney Dis 53:S11-104
2. Kalantar-Zadeh K, Tortorici AR, Chen JL, Kamgar M, Lau WL, Moradi H, Rhee CM, Streja E, Kovesdy CP (2015) Dietary restrictions in dialysis patients: is there anything left to eat? Semin Dial 28:159–168
3. Morris A, Lycett D (2020) Experiences of the dietary management of serum potassium in chronic kidney disease: interviews with UK adults on maintenance hemodialysis. J Ren Nutr 30:556–560

4. Clase CM, Carrero JJ, Ellison DH, Grams ME, Hemmelgarn BR, Jardine MJ, Kovesdy CP, Kline GA, Lindner G, Obrador GT, Palmer BF, Cheung M, Wheeler DC, Winkelmayer WC, Pecoits-Filho R (2020) Potassium homeostasis and management of dyskalemia in kidney diseases: conclusions from a Kidney Disease: Improving Global Outcomes (KDIGO) Controversies Conference. Kidney Int 97:42–61
5. Noori N, Kalantar-Zadeh K, Kovesdy CP, Murali SB, Bross R, Nissenson AR, Kopple JD (2010) Dietary potassium intake and mortality in long-term hemodialysis patients. Am J Kidney Dis 56:338–347
6. St-Jules DE, Goldfarb DS, Sevick MA (2016) Nutrient non-equivalence: does restricting high-potassium plant foods help to prevent hyperkalemia in hemodialysis patients? J Ren Nutr 26:282–287
7. Smyth A, Dunkler D, Gao P, Teo KK, Yusuf S, O'Donnell MJ, Mann JF, Clase CM (2014) The relationship between estimated sodium and potassium excretion and subsequent renal outcomes. Kidney Int 86:1205–1212
8. Gritter M, Vogt L, Yeung SMH, Wouda RD, Ramakers CRB, de Borst MH, Rotmans JI, Hoorn EJ (2018) Rationale and design of a randomized placebo-controlled clinical trial assessing the renoprotective effects of potassium supplementation in chronic kidney disease. Nephron 140:48–57
9. Picard K, Barreto Silva MI, Mager D, Richard C (2020) Dietary potassium intake and risk of chronic kidney disease progression in predialysis patients with chronic kidney disease: a systematic review. Adv Nutr 11:1002–1015
10. Sabatino A, Regolisti G, Gandolfini I, Delsante M, Fani F, Gregorini MC, Fiaccadori E (2017) Diet and enteral nutrition in patients with chronic kidney disease not on dialysis: a review focusing on fat, fiber and protein intake. J Nephrol 30:743–754
11. Carrero JJ, González-Ortiz A, Avesani CM, Bakker SJL, Bellizzi V, Chauveau P, Clase CM, Cupisti A, Espinosa-Cuevas A, Molina P, Moreau K, Piccoli GB, Post A, Sezer S, Fouque D (2020) Plant-based diets to manage the risks and complications of chronic kidney disease. Nat Rev Nephrol 16:525–542
12. Krishnamurthy VM, Wei G, Baird BC, Murtaugh M, Chonchol MB, Raphael KL, Greene T, Beddhu S (2012) High dietary fiber intake is associated with decreased inflammation and all-cause mortality in patients with chronic kidney disease. Kidney Int 81:300–306
13. Clegg DJ, Headley SA, Germain MJ (2020) Impact of dietary potassium restrictions in CKD on clinical outcomes: benefits of a plant-based diet. Kidney Med 2:476–487
14. Chauveau P, Aparicio M, Bellizzi V, Campbell K, Hong X, Johansson L, Kolko A, Molina P, Sezer S, Wanner C, Ter Wee PM, Teta D, Fouque D, Carrero JJ (2018) Mediterranean diet as the diet of choice for patients with chronic kidney disease. Nephrol Dial Transplant 33:725–735
15. Kelly JT, Palmer SC, Wai SN, Ruospo M, Carrero JJ, Campbell KL, Strippoli GF (2017) Healthy dietary patterns and risk of mortality and ESRD in CKD: a meta-analysis of cohort studies. Clin J Am Soc Nephrol 12:272–279
16. Chen X, Wei G, Jalili T, Metos J, Giri A, Cho ME, Boucher R, Greene T, Beddhu S (2016) The associations of plant protein intake with all-cause mortality in CKD. Am J Kidney Dis 67:423–430
17. Schwartz GJ, Munoz A, Schneider MF, Mak RH, Kaskel F, Warady BA, Furth SL (2009) New equations to estimate GFR in children with CKD. J Am Soc Nephrol 20:629–637
18. Bellemans M DMM (2005) Maten en gewichten: handleiding voor een gestandardiseerde kwantificering van voedingsmiddelen., Brussels
19. Gezondheidsraad H (2016) Voedingsaanbevelingen voor België - 2016. . In: Advies nr. 9285. Tabel 18 aivvbkp (ed), Brussels
20. Cupisti A, Kovesdy CP, D'Alessandro C, Kalantar-Zadeh K (2018) Dietary approach to recurrent or chronic hyperkalaemia in patients with decreased kidney function. Nutrients 10:261
21. Desloovere A, Renken-Terhaerdt J, Tuokkola J, Shaw V, Greenbaum LA, Haffner D, Anderson C, Nelms CL, Oosterveld MJS, Paglialonga F, Polderman N, Qizalbash L, Warady BA, Shroff R, Vande Walle J (2021) The dietary management of potassium in children with CKD stages 2–5 and on dialysis-clinical practice recommendations from the Pediatric Renal Nutrition Taskforce. Pediatr Nephrol 36:1331–1346
22. Chen W, Ducharme-Smith K, Davis L, Hui WF, Warady BA, Furth SL, Abraham AG, Betoko A (2017) Dietary sources of energy and nutrient intake among children and adolescents with chronic kidney disease. Pediatr Nephrol 32:1233–1241
23. Sherman RA, Mehta O (2009) Potassium in food additives: something else to consider. J Ren Nutr 19:441–442
24. Picard K (2019) Potassium additives and bioavailability: are we missing something in hyperkalemia management? J Ren Nutr 29:350–353
25. Naismith DJ, Braschi A (2008) An investigation into the bioaccessibility of potassium in unprocessed fruits and vegetables. Int J Food Sci Nutr 59:438–450
26. Macdonald-Clarke CJ, Martin BR, McCabe LD, McCabe GP, Lachcik PJ, Wastney M, Weaver CM (2016) Bioavailability of potassium from potatoes and potassium gluconate: a randomized dose response trial. Am J Clin Nutr 104:346–353
27. Ramos CI, González-Ortiz A, Espinosa-Cuevas A, Avesani CM, Carrero JJ, Cuppari L (2021) Does dietary potassium intake associate with hyperkalemia in patients with chronic kidney disease? Nephrol Dial Transplant 36:2049–2057
28. González-Ortiz A, Xu H, Ramos-Acevedo S, Avesani CM, Lindholm B, Correa-Rotter R, Espinosa-Cuevas Á, Carrero JJ (2020) Nutritional status, hyperkalaemia and attainment of energy/protein intake targets in haemodialysis patients following plant-based diets: a longitudinal cohort study. Nephrol Dial Transplant 36:681–688
29. Morris A, Krishnan N, Kimani PK, Lycett D (2020) Effect of dietary potassium restriction on serum potassium, disease progression, and mortality in chronic kidney disease: a systematic review and meta-analysis. J Ren Nutr 30:276–285
30. Winkler AW, Hoff HE, Smith PK (1941) The toxicity of orally administered potassium salts in renal insufficiency. J Clin Invest 20:119–126
31. Keith NM, Osterberg AE (1947) The tolerance for potassium in severe renal in-sufficiency: a study of ten cases. J Clin Invest 26:773–783
32. Allon M, Dansby L, Shanklin N (1993) Glucose modulation of the disposal of an acute potassium load in patients with end-stage renal disease. Am J Med 94:475–482
33. Parpia AS, L'Abbé M, Goldstein M, Arcand J, Magnuson B, Darling PB (2018) The impact of additives on the phosphorus, potassium, and sodium content of commonly consumed meat, poultry, and fish products among patients with chronic kidney disease. J Ren Nutr 28:83–90
34. El Amouri A, Snauwaert E, Foulon A, Vande Moortel C, Van Dyck M, Van Hoeck K, Godefroid N, Glorieux G, Van Biesen W, Vande Walle J, Raes A, Eloot S (2021) Dietary fibre intake is low in paediatric chronic kidney disease patients but its impact on levels of gut-derived uraemic toxins remains uncertain. Pediatr Nephrol 36:1589–1595
35. Kalantar-Zadeh K, Kopple JD, Deepak S, Block D, Block G (2002) Food intake characteristics of hemodialysis patients as obtained by food frequency questionnaire. J Ren Nutr 12:17–31
36. Ikizler TA, Burrowes JD, Byham-Gray LD, Campbell KL, Carrero JJ, Chan W, Fouque D, Friedman AN, Ghaddar S, Goldstein-Fuchs DJ, Kaysen GA, Kopple JD, Teta D, Yee-Moon Wang A,

Cuppari L (2020) KDOQI Clinical Practice Guideline for Nutrition in CKD: 2020 Update. Am J Kidney Dis 76:S1-s107
37. Clegg DJ, Hill Gallant KM (2019) Plant-based diets in CKD. Clin J Am Soc Nephrol 14:141–143
38. Goraya N, Simoni J, Jo C, Wesson DE (2012) Dietary acid reduction with fruits and vegetables or bicarbonate attenuates kidney injury in patients with a moderately reduced glomerular filtration rate due to hypertensive nephropathy. Kidney Int 81:86–93
39. Goraya N, Simoni J, Jo CH, Wesson DE (2013) A comparison of treating metabolic acidosis in CKD stage 4 hypertensive kidney disease with fruits and vegetables or sodium bicarbonate. Clin J Am Soc Nephrol 8:371–381
40. Goraya N, Simoni J, Jo CH, Wesson DE (2014) Treatment of metabolic acidosis in patients with stage 3 chronic kidney disease with fruits and vegetables or oral bicarbonate reduces urine angiotensinogen and preserves glomerular filtration rate. Kidney Int 86:1031–1038
41. Joshi S, Hashmi S, Shah S, Kalantar-Zadeh K (2020) Plant-based diets for prevention and management of chronic kidney disease. Curr Opin Nephrol Hypertens 29:16–21
42. Kelly JT, Rossi M, Johnson DW, Campbell KL (2017) Beyond sodium, phosphate and potassium: potential dietary interventions in kidney disease. Semin Dial 30:197–202
43. Hanson CS, Gutman T, Craig JC, Bernays S, Raman G, Zhang Y, James LJ, Ralph AF, Ju A, Manera KE, Teixeira-Pinto A, Viecelli AK, Alexander SI, Blydt-Hansen TD, Dionne J, McTaggart S, Michael M, Walker A, Carter S, Wenderfer SE, Winkelmayer WC, Bockenhauer D, Dart A, Eddy AA, Furth SL, Gipson DS, Goldstein SL, Groothoff J, Samuel S, Sinha A, Webb NJA, Yap HK, Zappitelli M, Currier H, Tong A (2019) Identifying important outcomes for young people with CKD and their caregivers: a nominal group technique study. Am J Kidney Dis 74:82–94
44. Aparicio-López C, Fernández-Escribano A, Garrido-Cantanero G, Luque-de Pablos A, Izquierdo-García E (2013) The influence of clinical situation on health-related quality of life in paediatric chronic kidney disease patients. Nefrologia 33:61–69