

Multidisciplinary Team versus a “Phosphate-Counting” App for Serum Phosphate Control: A Randomized Controlled Trial

Ana Cecilia Farfan-Ruiz,¹ Daniel Czikk,² Julie Leidecker,³ Tim Ramsay,⁴ Brendan McCormick,^{1,3} Kumanan Wilson,⁵ and Deborah Zimmerman ^{1,3}

Abstract

Background Hyperphosphatemia is almost universal in well-nourished patients with ESKD treated with dialysis due to an imbalance between dietary intake and phosphate removal via residual kidney function and dialysis. Although food phosphate content can vary dramatically between meals, the current standard is to prescribe a fixed dose of phosphate binder that may not match meal phosphate intake. The primary objective of our study was to determine if the use of an app that matches phosphate binder dose with food phosphate content would be associated with an improvement in serum phosphate and a reduction in calcium carbonate intake compared with the multidisciplinary renal team.

Methods Eighty patients with ESKD treated with peritoneal dialysis at a tertiary care hospital in Canada were randomized to the standard of care for serum phosphate management (multidisciplinary renal team) versus the OkKidney app. Serum phosphate was measured at baseline and then monthly for 3 months with adjustments to phosphate management as deemed necessary by the multidisciplinary team (control) or the phosphate binder multiplier in the OkKidney app (intervention) on the basis of the laboratory values. The primary analysis was an unpaired *t* test of the serum phosphate at study completion.

Results The participants were 56 (± 14) years old, and 54% were men; the most common cause of ESKD was diabetes mellitus. The serum phosphate values were 1.96 (0.41) and 1.85 (0.44) mmol/L in the control and intervention groups, respectively, at the end of 3 months ($P=0.30$). The median elemental daily dose of calcium carbonate did not differ between the groups at study completion (587 mg [309–928] versus 799 mg [567–1183], $P=0.29$).

Conclusions The OkKidney app was associated with similar but not superior serum phosphate control to the standard of care, which included renal dietician support.

Clinical Trial registry name and registration number: US National Library Medicine ClinicalTrials.gov, NCT01643486

KIDNEY360 2: 290–297, 2021. doi: <https://doi.org/10.34067/KID.0007132020>

Introduction

Maintenance of serum phosphate within the normal range remains a challenge for patients with ESKD treated with dialysis such that hyperphosphatemia is almost universal in well-nourished patients (1–4). Elevated serum phosphate levels have been associated with abnormal bone mineral metabolism, vascular and soft tissue calcification, cardiovascular morbidity, and mortality in patients with ESKD treated with dialysis (5–10).

Hyperphosphatemia management includes (1) removal of phosphate with dialysis, (2) reduction of dietary phosphate intake, and (3) the use of phosphate binders with meals. Convectional dialysis as an

independent strategy is insufficient for correcting abnormal serum phosphate concentration and leaves patients in a positive phosphate balance (11,12). Although dietary restrictions have been shown to be effective, efforts by dietitians are often hindered due to poor patient adherence and the extensive patient education required (13–15). Finally, phosphate binders, such as calcium carbonate, are useful but have potential complications, including a predisposition for hypercalcemia (11). Although food phosphate content can vary dramatically between meals, the current standard is to prescribe a fixed dose of phosphate binder with each meal that does not necessarily match phosphate intake

¹Division of Nephrology, Department of Medicine, University of Ottawa, Ottawa, Ontario, Canada

²Faculty of Medicine, University of Ottawa, Ottawa, Ontario, Canada

³Kidney Research Centre of the Ottawa Hospital Research Institute, Ottawa, Ontario, Canada

⁴Methods Centre, Ottawa Hospital Research Institute, School of Epidemiology and Public Health, University of Ottawa, Ottawa, Ontario, Canada

⁵Department of Medicine, University of Ottawa, Ottawa Hospital Research Institute, Ottawa, Ontario, Canada

Correspondence: Deborah Zimmerman, Department of Medicine, Ottawa Hospital, Ottawa Hospital Research Institute, University of Ottawa, 1967 Riverside Drive, Ottawa, ON, Canada K0A 2Z0. Email: dzimmerman@toh.ca

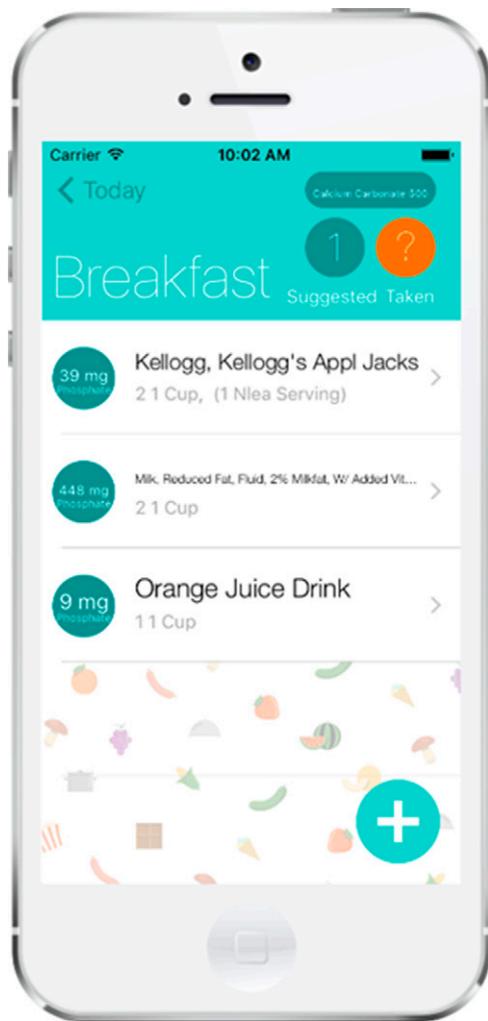


Figure 1. | Phosphate-counting application.

(16). This practice increases the likelihood of misdosing, where underdosing results in elevated serum phosphate levels and overdosing increases the risk for hypercalcemia and greater pill burden (17).

Given the surge of technological access in the last decade, mobile applications (apps) have proven to be effective for chronic disease self-management (18,19). We developed a phosphate-counting mobile app on Apple iOS (OkKidney) for patients with ESKD treated with peritoneal dialysis that calculates a phosphate binder dose appropriate for the phosphate content of a specific meal. In a proof-of-concept study using a β -version of the app, participants stated that the app was easy to use and deemed useful for self-management, thereby warranting a larger study (20). The primary objective of our study was to determine if the use of the OkKidney app compared with the standard of care was associated with (1) an improvement in serum phosphate and secondarily, (2) a reduction in overall calcium carbonate intake.

Materials and Methods

The study and all amendments were approved by the Ottawa Health Science Research Ethics Board (20170190–01H)

and registered with U.S National Library of Medicine (clinicaltrials.gov; NCT01643486) as part of a three-phase study. The study was conducted in adherence to the Declaration of Helsinki. Eligible patients with ESKD treated with peritoneal dialysis were recruited from the Ottawa Hospital, Ottawa, Ontario, Canada from November 2017 to December 2019. Inclusion criteria were (1) age >18 years, (2) taking phosphate binders, and (3) English or French speaking/writing. Exclusion criteria were (1) known cognitive dysfunction that might interfere with ability to participate, (2) unable or unwilling to give informed consent, (3) hypercalcemia, (4) visual or hearing impairment, or (5) expected renal transplant during the time of the study.

After obtaining informed consent, patients were randomized by the research coordinator using a computer-generated randomization sequence stored in sealed opaque envelopes to either receive the current standard of care for managing serum phosphate (multidisciplinary team that includes renal dietician) or use the OkKidney app that matches phosphate binders to meal phosphate content. Baseline laboratory tests of calcium, albumin, phosphate, and parathyroid hormone (PTH) were obtained prior to the start of the 3-month treatment period.

Both the intervention and control groups had received education on the renal diet with a registered dietician, including when to take their phosphate binders prior to study start. The intervention participants were shown how to input individual meal components into the app; the Health Canada Canadian nutrient file database was used to calculate phosphate content, which was visually displayed for educational purposes (Figure 1). A meal phosphate “multiplier” was determined on the basis of previous studies, the patient’s current phosphate binder dose, and serum phosphate control (16). The multiplier was used by the app to calculate how many phosphate binder pills were to be recommended with each meal. As a safety and efficacy feature, the app was designed to recommend a maximum of 2400 mg of elemental calcium in a day as continuing to increase the dose of phosphate binder is unlikely to have much effect on decreasing phosphate absorption and may contribute to hypercalcemia (21). The app was programmed to automatically account for the differences in binder efficacy between calcium carbonate and sevelamer hydrochloride (22).

Serum calcium and phosphate were measured monthly in both groups to evaluate serum phosphate control. If serum phosphate levels were not within the desired range, the “multiplier” was increased or decreased in the app by the research team in an effort to correct them. Interventions in the control group were at the discretion of the patient’s usual multidisciplinary health care team and included ongoing support from the registered dietician as required. PTH was repeated at study completion. Doses of vitamin D and the dialysis prescription were to remain constant as much as possible throughout the study.

Both groups were provided with phosphate binder medication on the basis of their current prescription (calcium carbonate or sevelamer hydrochloride), and pill counts were performed at study completion to determine total daily phosphate binder intake. The intervention group completed a prestudy technology readiness index (TRI) and a poststudy survey of satisfaction with the app (20,23). We retrospectively

recalculated the TRI, splitting the app users into two groups (group 1: those who completed the study or were withdrawn secondary to modality transfer or admission to hospital; group 2: those who withdrew from the study early due to difficulties with the app, lack of ongoing interest in the study, or personal reasons—the latter two categories were presumed to be secondary to challenges with the app).

Results are expressed as means and SDs or medians and interquartile ranges (IQRs) for continuous data and percentages and frequencies for categorical data as appropriate. Plots were constructed for both the intervention and control groups to assess changes in serum phosphate as a function of the baseline serum phosphate. The planned primary analysis was an unpaired *t* test, comparing the 3-month serum phosphate between intervention and control groups. As a secondary analysis, we performed unpaired *t* tests on the change in serum phosphate from baseline to the ends of month 1, month 2, and month 3. The daily elemental calcium carbonate dose taken during the study was calculated on the basis of pill counts for those participants who returned their study medication. Sevelamer hydrochloride was converted

to calcium carbonate equivalent dosing for the purpose of this analysis in 0.60–1.0 ratio (22). Analyses were done with SPSS Statistics 26.0 (IBM).

Results

Eighty patients were recruited to participate in the study. We calculated that 80 patients would be required to detect a difference of 0.29 mmol/L mmHg in serum phosphate (average of educational studies) with a standard deviation of 0.46 mmol/L, a two-sided alpha of 0.05, and a power of 80. Sixty-three participants completed the study: 36 in the control group and 27 in the intervention group (Figure 2). Reasons for withdrawal from the study in the control group included death ($N=2$), received a kidney transplant ($N=1$), and switched to hemodialysis ($N=1$). Reasons for withdrawal from the study in the intervention group included frustration with the app ($N=5$), switch to hemodialysis ($N=2$), received a kidney transplant ($N=2$), intensive care unit admission ($N=1$), no longer required phosphate binders

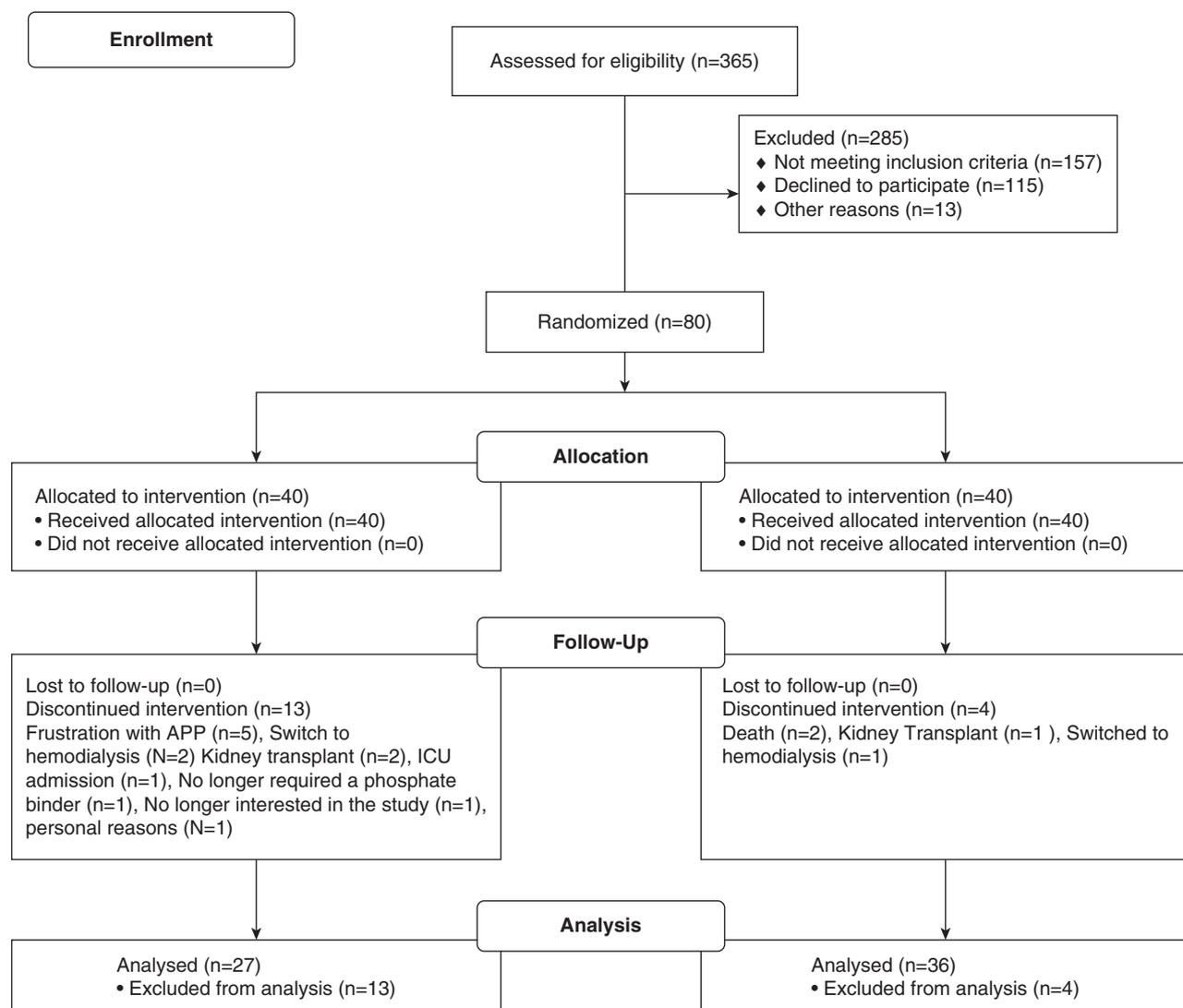


Figure 2. | Study flow diagram. ICU, intensive care unit.

($N=1$), no longer interested in the study ($N=1$), and personal reasons ($N=1$).

The patients were 56 (± 14) years old, and 54% were men (Table 1). The most common cause of ESKD requiring dialysis was diabetes mellitus. The participants had been treated with dialysis for 185 (± 196) days (control) and 304 (± 295) days (intervention). The median (IQR) elemental daily doses of calcium as a phosphate binder on the basis of the participant's current prescription were 900 mg (IQR, 600–1200) and 800 mg (IQR, 600–1200) for the control and intervention groups, respectively. More patients in the control group were taking calcitriol. The baseline serum phosphate, serum calcium, and PTH were similar between the two groups.

The baseline mean (SD) serum phosphate values were 2.04 (0.61) and 1.94 (0.50) mmol/L in the control and intervention arms, respectively. The reduction in serum phosphate over 3 months was much more dramatic in both groups for patients with poorly controlled phosphate at the beginning of the study (Figure 3). After 3 months, the mean (SD) serum phosphate values were 1.96 (0.41) and 1.85 (0.44) mmol/L in the control and intervention groups, respectively (Table 2). This difference was not statistically significant ($P=0.30$). The change in serum phosphate was

also not different between in the control and intervention arms (-0.06 [0.46] versus -0.04 [0.31], respectively; $P=0.82$). The median (IQR) elemental daily doses of calcium were 587 mg (309–928) and 799 mg (567–1183; $P=0.29$) for the control and intervention groups, respectively, at 3 months on the basis of pill counts (Table 2).

The average TRI score was 3.20 (0.50) of a maximum of 5.0 for the entire app group of participants (Table 3). The TRI was similar for those who completed the study using the app (or withdrew secondary to modality switch or hospital admission) and those who withdrew due to frustration with the app. The average age of the two groups was not different; the percentages of women were 58% in the first group and 29% in the second group. Thirty-seven participants completed the postsurvey on the assessment of the app, including four who withdrew from the study early secondary to difficulties using the app (Table 4). The majority of participants had a favorable experience with the app. However, nine of 37 participants reported that the app was hard to use and that they would not be interested in using it again. Thirty-three of 37 participants stated that the app improved their understanding of food-specific phosphate amounts and their confidence in controlling their phosphate intake. Additional comments submitted by patients suggested

Table 1. Baseline characteristics

Study Population Baseline Characteristics	Control, $N=40$	Intervention, $N=40$
Age, yr, mean (SD)	56.7 (15.3)	55.2 (12.6)
Men, N (%)	24 (60)	19 (48)
Women, N (%)	16 (40)	21 (52)
Race, N (%)		
White	31 (78)	29 (73)
Aboriginal	1 (2)	0
Asian	4 (10)	8 (20)
Other	4 (10)	3 (7)
Diabetes mellitus, N (%)		
Type 1	1 (2)	3 (8)
Type 2	16 (40)	20 (50)
Causes of ESKD, N (%)		
Diabetes mellitus	15 (40)	20 (50)
PCKD	3 (8)	4 (10)
GN	10 (26)	8 (20)
Other/unknown	10 (26)	8 (20)
Medications		
Calcium carbonate, N (%)	35 (88) ^a	39 (98)
Total elemental calcium dose, g, median (IQR, 25%–75%)	900 (600–1200)	800 (600–1200)
Sevelamer hydrochloride, N (%)	4 (10)	2 (5)
Total daily Renagel dose	4000 (800)	4267 (2571)
α -Calcidiol, N (%)	0 (0)	1 (2)
Calcitriol, N (%)	21 (53)	12 (30)
Calcitriol dose per week, μ g, mean (IQR, 25%–75%)	1.5 (0.75–1.75)	1.12 (0.75–1.68)
Cholecalciferol, N (%)	13 (33)	12 (30)
Cholecalciferol dose per day (IU), mean (SD)	1169 (373)	1066 (463)
Laboratory values		
Phosphate, mmol/L, mean (SD)	2.04 (0.61)	1.94 (0.50)
Calcium, mmol/L, mean (SD)	2.16 (0.17)	2.28 (0.19)
Albumin, g/L, mean (SD)	31.6 (5.5)	32.1 (4.6)
PTH, pmol/L, median (IQR, 25%–75%)	34.7 (24.3–48.2)	30.4 (18.6–70.2)
Kt/V, weekly, mean (SD)	1.97 (0.46)	2.02 (0.35)
CrCl, ml/min, mean (SD)	77.03 (23.51)	75.28 (17.18)

PCKD, polycystic kidney disease; IQR, interquartile range; PTH, parathyroid hormone, CrCl, creatinine clearance.

^aOne patient at baseline was taking calcium acetate.

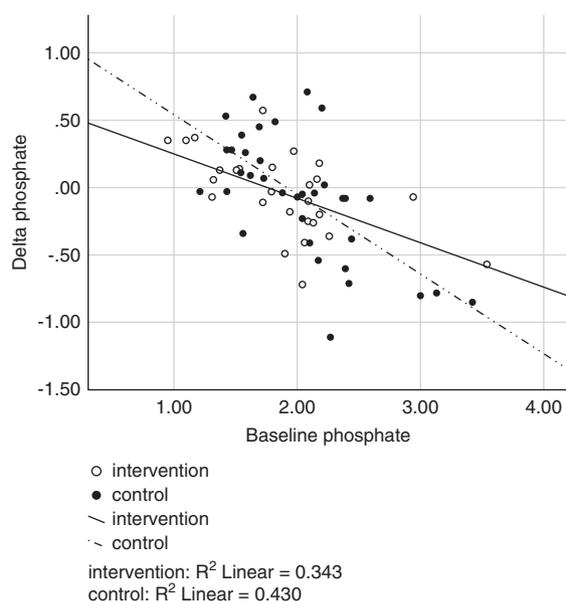


Figure 3. | Scatterplot of the effect of baseline serum phosphate.

that the app could be improved with the addition of more food options as well as the option to input unique recipes that were not programmed into the app.

Discussion

Almost all well-nourished patients with ESKD treated with dialysis have an elevated serum phosphate; management includes altering the dialysis prescription, dietary phosphate restriction, and phosphate binders. Intensive dietary education has been associated with improvements in serum phosphate, but control is often suboptimal (24). In one program, patients are taught how to calculate meal phosphate units and match those with the appropriate amount of phosphate binders; 180 picture cards are used for training (25). Because of this complexity of “phosphate” meal counting, most patients are prescribed a fixed number of phosphate binders with each meal. We hypothesized that

the use of a phosphate-counting app that matched the phosphate meal content with the appropriate amount of phosphate binder would be associated with improved serum phosphate control and a reduction in phosphate binder daily dose. The OkKidney app was associated with similar but not superior serum phosphate control compared with the standard of care that included a registered dietician, despite the assertion by most patients that the app improved their understanding of food-specific phosphate amounts and their confidence in controlling their phosphate intake. There are several possible explanations for this, including technology readiness, study and app design, source of phosphate, and overall phosphate binding.

Technology readiness is an individual’s innate propensity to adopt and utilize a new technology to achieve a goal in home or work life; measurement is possible using the TRI (23). In our previous study using the β -version of OkKidney, the TRI score was 3.66 of a maximum of five (20). In this study, the overall average TRI score was lower. However, for those individuals who withdrew from the study early secondary to difficulties with the app, the TRI score was similar, suggesting that this index could not be used as a screening tool for adopters of this particular app. Although the use of digital health products is common, health app users are more likely to be younger, be more educated, and have a higher income (26). The participants in our study who withdrew due to difficulties with the app were of similar age to the participants who continued in the study. Interestingly, women seemed to be less likely to withdraw from the study related to difficulties with the app. This is consistent with other studies in which men are more likely than women to terminate therapies (27). We did not collect data on education and income, and therefore, we cannot comment on their relevance to this study.

Neither the study participants nor the home dialysis unit clinicians were blinded to group allocation. Participants in the control group may have received additional counseling associated with the monthly laboratory tests, resulting in unexpected improvements serum phosphate. This may have played a small role as serum phosphate was slightly lower at study completion compared with baseline. Participants in the intervention group were expected to input each

Table 2. Study completion values

End of Study Laboratory Values and Phosphate Binder Intake	Control	Intervention	<i>P</i> Value
Phosphate, mmol/L, mean (SD)	1.96 (0.41) <i>N</i> =36	1.85 (0.44) <i>N</i> =27	0.30
Change in serum phosphate (baseline to month 1), mean (SD)	-0.14 (0.46) <i>N</i> =23	-0.08 (0.30) <i>N</i> =33	0.59
Change in serum phosphate (baseline to month 2), mean (SD)	-0.15 (0.50) <i>N</i> =29	0.10 (0.31) <i>N</i> =30	0.02
Change in serum phosphate (baseline to month 3), mean (SD)	-0.06 (0.46) <i>N</i> =35	-0.04 (0.31) <i>N</i> =27	0.82
Calcium, mmol/L, mean (SD)	2.22 (0.16)	2.23 (0.48)	
PTH, pmol/L, median (IQR, 25%–75%)	46.6 (24.4–59.2)	33.3 (16.7–49.3)	
Total elemental calcium, mg/d, median (IQR, 25%–75%)	587 (309–928) <i>N</i> =27	799 (567–1183) <i>N</i> =21	0.29

PTH, parathyroid hormone; IQR, interquartile range.

Table 3. Technology readiness scores

TRI Groups	Optimism	Innovativeness	Discomfort	Insecurity	TRI Score
Total (40), mean (SD)	4.27 (0.70)	3.14 (1.23)	2.34 (0.81)	3.45 (0.93)	3.2 (0.50)
Group 1 (33), mean (SD)	4.33 (0.58)	3.10 (1.28)	2.23 (0.77)	3.37 (0.95)	3.2 (0.50)
Group 2 (7), mean (SD)	4.00 (1.14)	3.46 (0.89)	2.86 (0.86)	3.82 (0.79)	3.2 (0.57)

meal for the duration of the study. This may have led to “study fatigue” in a small number of individuals, especially if they typically ate the same meal on multiple occasions and were unlikely to be receive new binder information from the app. In a recent systematic review in which 344 behavior change apps were identified, most were found to have low to moderate functionality (28). The majority of apps also had low- to moderate-behavior change techniques included within the app. Although the majority of participants in our study had a favorable experience with the app, nine of 37 reported that the app was difficult to use. They cited a limited number of food options and the inability to input specific recipes as limitations. Future iterations would need to incorporate these changes. Additional features could be added to the app, such as graphic displays of mineral metabolism control and percentage of foods eaten from the first two levels of the food pyramid, in an attempt to affect behavior change (29).

The OkKidney app was not designed to adjust phosphate binder dose on the basis of food phosphorous bioavailability (29). It is possible that the amount of phosphate binder recommended was overestimated when the meal phosphate content was primarily from plant sources (30). Although we used a national food phosphate content database, many phosphate additives remain hidden such that the recommended phosphate binder dose would be underestimated. This is a major issue for patients with ESKD treated with dialysis whether they are supported by a multidisciplinary team or with the app and results in the prescription of more phosphate binders with meals if the serum phosphate increases. Lastly, the app is unable to account for the amount of readily available phosphate present in medications (31).

The daily dose of elemental calcium carbonate decreased during the study, with no difference between the intervention and control groups at study completion. The initial dose

was on the basis of the participant’s baseline phosphate binder prescription; the final dose was on the basis of pill counts. Only 45% of United States patients on dialysis reported taking all of their prescribed phosphate binders in the previous month, suggesting that the baseline calcium carbonate dose was likely an overestimate of the amount of phosphate binder actually taken by the control and intervention groups (32). Not all participants returned their phosphate binder at study completion, raising additional concerns about the reliability of pill counts (33).

Our study has several strengths and limitations. This is the first randomized controlled trial to use an app to assist patients in the self-management of serum phosphate. We have also been able to identify several modifications that could be made to the app to make it more user friendly. Although we included a representative patient population, many of the participants already had reasonable serum phosphate control, limiting our ability to detect any potential benefit of the app in assisting with patient self-management of serum phosphate. The number of patients who withdrew from the intervention arm also limited our ability to detect any possible superiority in serum phosphate control with the OkKidney app if it existed. Some of the patients did not return their phosphate binder medication for pill counts at study completion, potentially compromising our secondary outcome. A run-in phase in future trials may be helpful in identifying people who are unlikely to complete the study. Lastly, the lack of blinding and the single-center design may have introduced bias and limit generalizability.

In summary, the OkKidney app was associated with similar but not superior serum phosphate control to the standard of care, which included renal dietician support. The final daily phosphate binder doses were also similar in both groups. After addressing the issues identified by patients that would make the app more user friendly, it

Table 4. Postapp survey results

Question	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I found the app easy to use	5	4	5	12	11
I used the app for each meal during the study period	4	1	4	12	16
I would continue to use this app	5	3	7	13	9
Overall, I found the app useful ^a	2	3	4	9	18
After using this app, I have a better understanding of the phosphate levels for different food items	2	0	2	13	20
After using this app, I am more aware of how to control my phosphate intake	2	0	2	13	20

app, application.

^aOne respondent did not answer this question.

could be incorporated into clinical practice to facilitate ongoing patient education and management of serum phosphate, especially in programs with reduced access to renal dietitian support.

Disclosures

B. McCormick, K. Wilson, and D. Zimmerman report receiving salary support from the Department of Medicine at the Ottawa Hospital. D. Zimmerman reports receiving research funding from GSK; honoraria from Otsuka; being a scientific advisor or member with Otsuka; and other interests/relationships with Alive to Strive (not for profit) and the Canadian Society of Nephrology (past president). All remaining authors have nothing to disclose.

Funding

Financial assistance for the final phase of this three part study was by The Ottawa Hospital Academic Medical Organization (TOHAMO) Innovation Fund 2016-17 and the Jones Family Foundation.

Acknowledgments

The authors thank the mobile Health team at the Ottawa Hospital for their initial involvement in app design.

Author Contributions

B. McCormick and D. Zimmerman conceptualized the study; K. Wilson and D. Zimmerman were responsible for methodology; J. Leidecker and D. Zimmerman were responsible for data curation; D. Zimmerman was responsible for funding acquisition, investigation, and resources; D. Zimmerman provided supervision; D. Czikk, A.C. Farfan-Ruiz, and T. Ramsay were responsible for formal analysis; D. Czikk, A.C. Farfan-Ruiz, J. Leidecker, and D. Zimmerman wrote the original draft; and D. Czikk, A.C. Farfan-Ruiz, J. Leidecker, B. McCormick, T. Ramsay, K. Wilson, and D. Zimmerman reviewed and edited the manuscript.

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Received: November 30, 2020 Accepted: December 14, 2020