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 Zimmerman1,3

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 dietitian support.

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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. Conventional 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 diabeticians 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
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

Figure 1. | Phosphate-counting application.
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 0.80. 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)* | 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, µg, 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) | 79.28 (17.18) |

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

*One patient at baseline was taking calcium acetate.
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 dietitian, 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 | P Value |
|----------------------------------------------------------|---------|--------------|---------|
| Phosphate, mmol/L, mean (SD)                             | 1.96 (0.41) | 1.85 (0.44) | 0.30    |
| N=36                                                      | N=27    |
| Change in serum phosphate (baseline to month 1), mean (SD)| -0.14 (0.46) | -0.08 (0.30) | 0.59    |
| N=23                                                      | N=33    |
| Change in serum phosphate (baseline to month 2), mean (SD)| -0.15 (0.50) | 0.10 (0.31) | 0.02    |
| N=29                                                      | N=30    |
| Change in serum phosphate (baseline to month 3), mean (SD)| -0.06 (0.46) | -0.04 (0.31) | 0.82    |
| N=35                                                      | N=27    |
| 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) | 799 (567–1183) | 0.29    |
| N=27                                                      | N=21    |

PTH, parathyroid hormone; IQR, interquartile range.
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 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 dietitian 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

| 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                                          | 2                 | 3        | 4       | 9     | 18             |
| After using this app, I have a better understanding of the phosphate     | 2                 | 0        | 2       | 13    | 20             |
| levels for different food items                                          |                   |          |         |       |                |
| After using this app, I am more aware of how to control my phosphate     | 2                 | 0        | 2       | 13    | 20             |
| intake                                                                   |                   |          |         |       |                |

*One 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 dietician support.

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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. Czik, A.C. Farfan-Ruiz, and T. Ramsay were responsible for formal analysis; D. Czik, A.C. Farfan-Ruiz, J. Leidecker, and D. Zimmerman wrote the original draft; and D. Czik, A.C. Farfan-Ruiz, J. Leidecker, B. McCormick, T. Ramsay, K. Wilson, and D. Zimmerman reviewed and edited the manuscript.

References
1. Noordzij M, Korevaar JC, Boeschoten EW, Dekker FW, Bos WJ, Krediet RT: Netherlands Cooperative Study on the Adequacy of Dialysis (NCEOSAD) Study Group: The Kidney Disease Outcomes Quality Initiative (K/DOQI) guideline for bone metabolism and disease in CKD: Association with mortality in dialysis patients. Am J Kidney Dis 46: 925–932, 2005 https://doi.org/10.1053/j.ajkd.2005.08.013
2. Blayney MJ, Tentori F: Trends and consequences of mineral bone disorder in haemodialysis patients: Lessons from The Dialysis Outcomes and Practice Patterns Study (DOPPS). J Ren Care 35 [Suppl 1]: 7–13, 2009 https://doi.org/10.1111/j.1575-6686.2009.00048.x
3. Young EW, Akiba T, Albert JM, McCarthy JT, Kerr PG, Mendelsohn DC, Jadoul M: Magnitude and impact of abnormal mineral metabolism in hemodialysis patients in the Dialysis Outcomes and Practice Patterns Study (DOPPS). Am J Kidney Dis 43[Suppl 2]: 34–38, 2004 https://doi.org/10.1016/S0272-6386(04)01103-5
4. Al Aly Z, González EA, Martin KJ, Gallens ME: Achieving K/DOQI laboratory target values for bone and mineral metabolism: An uphill battle. Am J Nephrol 24: 422–426, 2004 https://doi.org/10.1159/000080087
5. Martin KJ, González EA: Prevention and control of phosphate retention/hyperphosphatemia in CKD-MBD: What is normal, when to start, and how to treat? Clin J Am Soc Nephrol 6: 440–446, 2011 https://doi.org/10.2215/CJN.05130610
6. Delmez JA, Slatopolsky E: Hyperphosphatemia: Its consequences and treatment in patients with chronic renal disease. Am J Kidney Dis 19: 303–317, 1992 https://doi.org/10.1016/S0272-6386(12)80446-X
7. Lowrie EG, Lew NL: Death risk in hemodialysis patients: The predictive value of commonly measured variables and an evaluation of death rate differences between facilities. Am J Kidney Dis 15: 458–482, 1990 https://doi.org/10.1016/S0272-6386(12)70364-5
8. Block GA, Klassen PS, Lazarus JM, Ofshtun N, Lowrie EG, Chertow GM: Mineral metabolism, mortality, and morbidity in maintenance hemodialysis. J Am Soc Nephrol 15: 2208–2218, 2004 https://doi.org/10.1097/01.ASN.0000133041.27682.A2
9. Ansell D: Serum phosphate and outcomes in PD patients. Nephrol Dial Transplant 22: 667–668, 2007 https://doi.org/10.1093/ndt/gfl593
10. Slinin Y, Foley RN, Collins AJ: Calcium, phosphorus, parathyroid hormone, and cardiovascular disease in hemodialysis patients: The USRDS waves 1, 3, and 4 study. J Am Soc Nephrol 16:1788–1793, 2005 https://doi.org/10.1681/ASN.2004040275
11. Coladonato JA: Control of hyperphosphatemia among patients with ESRD. J Am Soc Nephrol 16[Suppl 1]: S107–S114, 2005 https://doi.org/10.1681/ASN.2005060663
12. Sedlacek M, Dimanoff F, Urzibarri J: Relationship between phosphorus and creatinine clearance in peritoneal dialysis: Clinical implications. Am J Kidney Dis 36: 1020–1024, 2000 https://doi.org/10.1053/ajkd.2000.19105
13. Denhaerynck K, Manhaeve D, Dobbels F, Garzoni D, Nolte C, De Geest S: Prevalence and consequences of nonadherence to hemodialysis regimens. Am J Crit Care 16: 222–235, 2007
14. Kügler C, Maeding I, Russell CL: Non-adherence in patients on chronic hemodialysis: An international comparison study. J Nephrol 24: 366–375, 2011 https://doi.org/10.5301/JN.2010.5823
15. Griva K, Lai AY, Lim HA, Yu Z, Foo MW, Newman SP: Non-adherence in patients on peritoneal dialysis: A systematic review. PLoS One 9:e89001, 2014 https://doi.org/10.1371/journal.pone.0089001
16. Leung S, McCormick B, Wagner J, Biyani M, Lavoie S, Imtiaz R, Zimmerman D: Meal phosphate variability does not support fixed dose phosphate binder schedules for patients treated with peritoneal dialysis: A prospective cohort study. BMC Nephrol 16: 205, 2015 https://doi.org/10.1186/s12882-015-0205-3
17. Chiu YW, Teitelbaum I, Misra M, de Leon EM, Adzize T, Mehrotra R: Pill burden, adherence, hyperphosphatemia, and quality of life in maintenance dialysis patients. Clin J Am Soc Nephrol 10: 1089–1096, 2009 https://doi.org/10.2215/CJN.00290109
18. Kebede MM, Zeeb H, Peters M, Heise TL, Pischke CR: Effectiveness of digital interventions for improving glycemic control in persons with poorly controlled type 2 diabetes: A systematic review, meta-analysis, and meta-regression analysis. Diabetes Technol Ther 20: 767–782, 2018 https://doi.org/10.1089/dia.2018.0216
19. Kirwan M, Vandenlantelo C, Fenning A, Duncan MJ: Diabetes self-management smartphone application for adults with type 1 diabetes: Randomized controlled trial. J Med Internet Res 15:e235, 2013 https://doi.org/10.2196/jmir.2588
20. Imtiaz R, Atkinson K, Guerinet J, Wilson K, Leidecker J, Zimmerman D: A pilot study of OkKidney, a phosphate counting application in patients on peritoneal dialysis. Perit Dial Int 37: 613–618, 2017
21. Sherman RA: Hyperphosphatemia in dialysis patients: Beyond nonadherence to diet and binders. Am J Kidney Dis 67: 182–186, 2016 https://doi.org/10.1053/j.ajkd.2015.07.035
22. Daugirdas JT, Finn WF, Emmett M, Chertow GM; Frequent Hemodialysis Network Trial Group: The phosphate binder equivalence of sevelamer hydrochloride and calcium carbonate in maintenance hemodialysis patients. Semin Dial 24: 41–49, 2011 https://doi.org/10.1111/j.1525-139X.2011.00849.x
23. Parasaruman AP, Colby C: An updated and streamlined technology readiness index: TRI 2.0. J Serv Res 18: 59–74, 2015 https://doi.org/10.1177/1094660514539730
24. Reddy V, Symes F, Sithi N, Scally AJ, Scott J, Muntaz R, Stoves J: Dietitian-led education program to improve phosphate control in a single-center hemodialysis population. J Ren Nutr 19: 314–320, 2009
25. Ahlenstiel T, Lipe P, Eriech JH, Kuhlmann MK: Self-adjustment of phosphate binder dose to meal phosphate content improves
management of hyperphosphataemia in children with chronic kidney disease. *Nephrol Dial Transplant* 25: 3241–3249, 2010 https://doi.org/10.1093/ndt/gfq161

26. Carroll JK, Moorhead A, Bond R, LeBlanc WG, Petrella RJ, Fiscella K: Who uses mobile phone health apps and does use matter? A secondary data analytics approach. *J Med Internet Res* 19: e125, 2017 https://doi.org/10.2196/jmir.5604

27. Sherman LD, Patterson MS, Tomar A, Wigfall LT: Use of digital health information for health information seeking among men living with chronic disease: Date from the health information national trends survey. *Am J Mens Health* 14: 1557988320901377, 2020 https://doi.org/10.1177/1557988320901377

28. McKay FH, Wright A, Shill J, Stephens H, Uccellini M: Using health and well-being apps for behavior change: A systematic search and rating of apps. *JMIR Mhealth Uhealth* 7: e11926, 2019 https://doi.org/10.2196/11926

29. D’Alessandro C, Piccoli GB, Cupisti A: The “phosphorus pyramid”: A visual tool for dietary phosphate management in dialysis and CKD patients. *BMC Nephrol* 16: 9, 2015 https://doi.org/10.1186/1471-2369-16-9

30. Moe SM, Zidehsarai MP, Chambers MA, Jackman LA, Radcliffe JS, Trevino LL, Donahue SE, Asplin JR: Vegetarian compared with meat dietary protein source and phosphorus homeostasis in chronic kidney disease. *Clin J Am Soc Nephrol* 6: 257–264, 2011 https://doi.org/10.2215/CJN.05040610

31. Nelson SM, Sarabia SRS, Christilaw E, Ward EC, Lynch SK, Adams MA, Holden RM: Phosphate-containing prescription medications contribute to the daily phosphate intake in a third of hemodialysis patients. *J Ren Nutr* 27: 91–96, 2017

32. Fissell RB, Karaboyas A, Bieber BA, Sen A, Li Y, Lopes AA, Akiba T, Bommer J, Ethier J, Jadoul M, Pisoni RL, Robinson BM, Tentori F: Phosphate binder pill burden, patient-reported non-adherence, and mineral bone disorder markers: Findings from the DOPPS. *Hemodial Int* 20: 38–49, 2016 https://doi.org/10.1111/hdi.12315

33. Vik SA, Maxwell CJ, Hogan DB, Patten SB, Johnson JA, Romonko-Slack L: Assessing medication adherence among older persons in community settings. *J Popul Ther Clin Pharmacol* 12: e152–e164, 2005

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