Improving Transplant Med Safety through a Pharmacist-Led, mHealth-Based Program

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Abstract

Purpose: The goal of this study was to examine the efficacy of improving medication safety through a pharmacist-led, mobile health–based intervention.

Scope: Clinical trial.

Methods: This was a 12-month, single-center, prospective, parallel, two-arm, single-blind, randomized, controlled trial. Adult kidney recipients 6–36 months post-transplant were eligible. Participants randomized to the intervention received supplemental, clinical pharmacist–led medication therapy monitoring and management via a mobile health–based application, integrated with risk-guided televisits and home-based BP and glucose monitoring. The application provided an accurate medication regimen, timely reminders, and side effect surveys. Both the control and intervention arms received usual care.

Results: Overall, 136 were included. The mean age was 51 years, 57% were men, and 64% were Black. Participants receiving the intervention experienced a significant reduction in medication errors (61% reduction in risk rate; incident risk ratio, 0.39; 95% confidence interval, 0.28 to 0.55; P, 0.001) and a significantly lower risk of grade 3 or higher adverse events (incident risk ratio, 0.55, 95% confidence interval, 0.30 to 0.99; P, 0.05). The intervention arm also demonstrated significantly lower rates of hospitalizations (incident risk ratio, 0.46; 95% confidence interval, 0.27 to 0.77; P, 0.005) and lower healthcare costs.

Keywords: Kidney Transplant, Medication Safety, Hospitalizations, mHealth, Pharmacist Interventions

Purpose

Primary Aim
- Determine the incidence, severity, and etiologies of med errors and adverse drug events in kidney transplant recipients and compare these between the intervention and control cohorts.

Secondary Aims
- Measure the total resources utilized (hospital, outpatient, staff effort) to provide care and compare these between the intervention and control cohorts.
- Measure the impact of med errors and adverse drug events on clinical outcomes, including acute rejections, infections, graft loss, and death (exploratory aim).

Scope

Within kidney transplantation, despite dramatic improvements in acute rejection rates, long-term graft survival has not improved to nearly the same degree. Since 2003, there has been a 50% reduction in acute rejection rates; yet, during this same time period, the kidney allograft half-life has only increased by a modest 0.6 years. The most recent report from the Scientific Registry of Transplant Recipients (SRTR) demonstrates a historically low 1-year acute rejection rate of <10%, with a suboptimal 5-year graft survival rate of 70%. Medication safety issues, which encompass both medication errors and adverse drug events, are a predominant cause of deleterious clinical outcomes in kidney transplant recipients; most notable of these outcomes is graft loss.

We and others have demonstrated that approximately two thirds of transplant recipients will experience at least one medication error. Of more concern, nearly one in eight kidney transplant recipients will experience a medication error that directly contributes to hospitalization and more than doubles the risk of graft loss. These medication errors are usually the result of unintentional medication nonadherence (MNA); patients have difficulty obtaining medications or forget to take medications in a timely fashion. MNA, usually due to unintentional patient-level factors, has now been recognized as a major contributor to late acute antibody-mediated rejection (AMR), the development of donor-specific antibodies (DSA), and subsequent graft loss. In a prospective, multicenter, observational study, 315 kidney transplant recipients were followed for roughly 3 years post-transplant; 47% of the 50 allografts that failed during follow-up were due to AMR. Thirty-two percent of patients were identified as having MNA, and approximately one half of all AMRs were due to MNA. Remarkably, MNA was 10 times more frequent in patients with graft failure (32% vs. 3%, p<0.001). As most MNA is unintentional, with the proper monitoring tools and clinical follow-up, this devastating risk factor appears to be modifiable.

Although contemporary immunosuppression is extremely effective at preventing rejection, adverse drug events are nearly universal and are associated with significant post-transplant morbidity. Several studies suggest that adverse drug events, particularly surrounding infection from over-immunosuppression and calcineurin inhibitor nephrotoxicity, may be a predominant cause for the discordance noted between reductions in acute rejection and lack of improvements in graft survival. In 2006, Parasuraman, et al. showed that infectious etiologies surpassed rejections as the leading cause of death-censored graft lost. Our formative research demonstrates that immunosuppressant adverse drug events are correlated with medication errors; patients that experience medication errors leading to hospitalization have 2.3 times the risk of developing at least three adverse drug events (p=0.020). In other chronic disease states, adverse drug events have been clearly established as a major risk factor for MNA. Therefore, early recognition of adverse drug events in kidney transplant recipients will likely help prevent

downstream clinical sequelae, including MNA and irreversible immunosuppressant toxicities. Research demonstrates that clinical pharmacists have the unique education and training to identify these events early while also developing strategies to mitigate or resolve the associated sequelae.

The impact of kidney allograft loss on clinical and economic outcomes cannot be overstated. Annual death rates are more than three times higher in those with kidney allograft failure (9.4%) than in those with a functioning transplant (2.8%). A well-functioning kidney allograft has also been shown to dramatically reduce the progression of cardiovascular disease and associated events. In terms of cost, kidney transplantation is clearly cost effective. However, due to high and varied perioperative costs associated with this surgery, the breakeven point can range from 2 to 11 years after transplant. Once a kidney allograft fails, patients return to dialysis, and costs to provide care accrue at a significantly higher rate. Our research indicates that kidney transplant recipients who experience clinically significant medication errors spend 5 more days in the hospital for readmissions, costing more than $18,000 per case. These data establish the need for innovative interventions designed to improve medication safety in kidney transplant recipients by reducing medication errors and adverse drug events. Such medication safety improvements are needed to demonstrate significant progression in the optimization of long-term graft outcomes and patient survival while considerably reducing the costs to provide high-value care in this high-risk group of patients. Control of chronic health conditions, exacerbated by immunosuppressive therapies, also has a major impact on allograft and patient survival. Due to the high prevalence of hypertension and diabetes in kidney transplant recipients and the interplay between these diseases and graft outcomes, this is an ideal population to test mHealth systems and their effects on outcomes for future application in a more widespread population.

Kidney transplantation is considered the preferred treatment option for patients with end-stage renal disease, with more than 140,000 patients living in the U.S. with a functioning transplant. The use of potent contemporary immunosuppression has significantly decreased acute rejection rates, with current 1-year rates of <10% compared with 30 to 40% three decades prior. Despite this, long-term renal allograft survival remains largely unchanged during this time. Studies have demonstrated that predominant causes of graft loss are driven by immunosuppression-related adverse drug events (patient harm related to a med) and rejection from med nonadherence. These origins of graft loss encompass issues directly related to med safety. Current immunosuppression regimens are highly effective but carry the burdens of considerable toxicities and exceeding complexity. These attributes place a transplant patient at high risk of developing adverse drug events and med errors. Despite this, there are limited studies analyzing the incidence, etiologies, and outcomes associated with med safety issues. Our formative research has demonstrated that med errors (taking a med in a manner not intended), predominantly due to patient-related factors, occur in nearly two thirds of kidney transplant recipients, leading to hospitalization in one out of every eight recipients. We also have found that recipients who develop clinically significant med errors are at considerably higher risk of deleterious clinical outcomes, most significantly graft loss; these patients also develop substantially more adverse drug events, readmissions, and acute rejections.

Our team has published noncontrolled quality improvement initiatives demonstrating reduced med errors, adverse drug events, hospital length of stay, and readmissions through pharmacist-led interventions. These studies provide foundational evidence that structured interventions can improve outcomes associated with med safety issues in transplant, but additional data are required both to better understand contributing risk and etiologies and to test effectiveness of novel interventions in a prospective, controlled manner. We have demonstrated feasibility and

high acceptability of mobile health (mHealth) technology to bridge communication gaps that often lead to med safety issues. Our transplant recipients have doubled smartphone use to over 60% from 2012 to 2015. Almost 90% of survey respondents indicated that they were comfortable with mHealth monitoring and felt that it improved timely patient-provider communication. Transplant recipients were central to successful development of a mHealth medical regimen self-management program, which the proposed program builds upon. These data establish that a pharmacist-empowered, patient-centered, mHealth-based intervention provides an innovative and promising opportunity to improve med safety in kidney transplantation. Our mHealth programs and that of others have been successful in improving physical markers for various chronic diseases, including those present in transplant recipients (e.g., BP for hypertension); however, cost effectiveness of these efforts have yet to be adequately demonstrated.

The central hypothesis for the TRANSAFE Rx study is that a mHealth technology–enabled pharmacist intervention will significantly reduce med safety issues and lead to reduced healthcare resource utilization in kidney transplantation. This study will provide novel data on the incidence and outcomes of med safety issues in transplantation while demonstrating the effectiveness of a pharmacist-led, patient-centered, mHealth intervention. The enduring goals of this study are to demonstrate a highly effective, efficient, and deployable method to improve med safety in a high-risk patient population and disseminate this mHealth-enabled program across multiple patient types and healthcare environments.

This was a single-center, randomized, controlled clinical trial conducted within a kidney transplant center. Patients were recruited from the outpatient kidney transplant clinic based on the following criteria:

Inclusion Criteria
1. Kidney transplant recipient between 6 and 36 months post-transplant
2. At least 18 years of age
3. Transplant MD agrees that patient is eligible to participate

Exclusion Criteria
1. Multi-organ recipient
2. Patient is incapable of:
    a. Measuring their own blood pressure
    b. Measuring their own glucose (if subject has diabetes)
    c. Self-administering medications
    d. Speaking, hearing, and reading English
    e. Utilizing the mHealth application, after training

Methods

Study Design

This was a single-center, 12-month, parallel, two-arm, single-blind, 1:1 randomized, controlled clinical trial involving 136 adult kidney transplant recipients (68 in each arm; NCT03247322). Comprehensive details of the study rationale and design have been published elsewhere. The primary aims were to assess the efficacy of a pharmacist-led, mobile health–based intervention on improving medication safety and health outcomes in kidney transplant recipients compared with usual care. This study was reviewed and approved by the Institutional Review Board at the Medical University of South Carolina.
Study Eligibility and Enrollment

Adult (18 years old at time of transplant) kidney recipients 6–36 months post-transplant were

eligible for the study. Multiorgan recipients were excluded, as were patients incapable of measuring their own BP and blood glucose (if applicable); self-administering medications; speaking, hearing, and reading English; or utilizing the mobile health application (app) after sufficient training. Patients who were eligible and agreed to study participation were consented and randomized by research personnel using a random number generator in a simple blocked manner (blocks of eight) into one of the two study arms. Only study coordinators and clinical pharmacists assessing medication errors, AEs, and clinical outcomes were blinded to study assignment.

Intervention

Participants randomized to the intervention arm were provided the same usual care as the control cohort. As part of usual care, kidney transplant recipients are seen by pharmacists while in the hospital and during routine clinic visits for the first 6 months post-transplant. After this, pharmacists see patients only when requested by a provider for medication-related issues. In addition to usual care, the intervention group received clinical pharmacist–led supplemental medication therapy monitoring and management utilizing a smartphone-enabled mobile health app, integrated with risk-driven televisits and home-based BP and blood glucose monitoring (when applicable). The mobile health app, developed by our group, provided participants with an accurate list of their medication regimen that was automatically updated from the electronic medical record (EMR), timely medication reminders, automated messages triggered by missed doses or scheduled health monitoring, medication side effect tracking, and BP and blood glucose trends (when applicable). Monthly and subject-initiated surveys were delivered through the app regarding the frequency and severity of common side effects. The intervention included clinical pharmacist telemonitoring of medications, medical appointment adherence, weekly BP/glucose readings, and scheduling of telehealth visits with participants. The clinical pharmacist was notified of any medication changes and transitions of care by subject self-report or via new medications reported in the EMR and was automatically notified of nonadherence (20% missed self-reported medication doses over a week), critical BP or blood glucose values, or alarming trends in readings or symptom assessments from surveys via rule-based algorithms. The pharmacist responded to alerts through communication with the participant and care team and updated the medication regimen in the EMR as necessary. Televisits enabled the pharmacist to conduct medication reviews to identify any medication safety issues, ensure accurate medications through transitions of care, screen for drug interactions, and provide recommendations to the participant. Full details on the development and validation of the mobile health app and dashboard are published elsewhere.

Measures and Data Collection

The coprimary outcomes were (1) the incidence and severity of medication errors and (2) the incidence and severity of AEs compared between the intervention and control arms. Medication errors were defined as the participant taking a different medication than intended, based on comparison of the EMR with the participant's reported regimen. The type of medication error was recorded and included both administrative and clinical subtypes. Administrative medication errors were defined as discrepancies on the EMR, including drug omissions, additions, dose errors, incorrect drug, incomplete dosage instructions, prescribing errors, and any prescribed drug that the participant was not taking. Clinical medication errors included duplicate therapy, no indication, untreated condition, high/low dose, contraindications, and other. Medication error severity was determined using a previously validated scale. AE type and severity were defined using the Common Terminology Criteria for Adverse Events. Infections were defined as any diagnosed and treated infection. Hospitalizations were defined as admission to a hospital with at least one overnight stay.

Data on medication errors, AEs, and clinical outcomes were collected by blinded study coordinators and clinical pharmacists who did not have access to the randomization module within the electronic case report form system (REDCap, https://www.project-redcap.org/).

Sample Size

We estimated that approximately 64% of transplant recipients in the control group would experience at least one medication error during the 12-month study. Prior research demonstrates that pharmacist-led interventions can produce up to a 50% reduction in these medication errors. A total sample size of 136 participants was needed to provide at least 80% power, accounting for dropouts, and detect a 50% reduction in medication errors. Given an estimated AE incidence rate of 87%, this sample size was also sufficiently powered to detect a 33% reduction in significant AEs. A comprehensive overview of the sample size calculation is included in the trial protocol.

Statistical Analyses

This analysis utilized intent-to-treat methodology. Data are reported using percentages for nominal and ordinal variables and compared using Fisher's exact test or Pearson's chi-squared test, as appropriate. Results are reported using means and SDs or medians and interquartile ranges, with statistical comparison using t tests or the Mann–Whitney U test. Multivariable modeling was also utilized to assess for the independent effect of the treatment intervention on endpoints. For count outcomes, we used Poisson or negative binomial regression models, depending on data dispersion and model fit. For the repeated measure outcome of medication errors (measured every 2 months during the 12-month study), we used generalized linear mixed modeling with a random intercept using likelihood methods and accounting for time and correlation of repeated measures within participants. The effect of the intervention over time was assessed using a time*treatment interaction term within the model. We report both unadjusted and adjusted outcomes. Multivariable models were adjusted for recipient age, sex, race, history of diabetes, years on dialysis, calculated panel reactive antibody, cold ischemic time, induction therapy, delayed graft function, cytomegalovirus (CMV) serostatus, and donor characteristics (donor type, kidney donor risk index). A two-sided P value <0.05 was considered statistically significant. SAS version 9.4 (SAS Institute, Cary, NC) was used for analyses.

Limitations
- Single center
- Lack of attention control
- Single blind
- Missing some assessments due to a lack of follow-up (48 total, 5% of all assessments)

Results

Between October 2017 and January 2019, 774 kidney recipients at the Medical University of South Carolina were screened for eligibility; 273 were approached for consent, and 136 kidney transplant recipients agreed to participate, provided informed written consent, and were enrolled in the study (68 in each arm). The most common reason for ineligibility was failure to meet the study window of 6–36 months post-transplant. Patients who were eligible and declined participation primarily were not interested in the study, were uncomfortable with the technology, or felt their medications and comorbidities were already well controlled.

Two participants withdrew from the study intervention arm before completing the study, for a 99% retention rate; both participants are included in this intent-to-treat analysis.

Baseline characteristics were mostly comparable between the two study arms. The mean age was 51 years, 57% of participants were men, and 64% were Black individuals. The primary etiologies of kidney failure were diabetes and hypertension, followed by polycystic kidney disease and lupus. History of hypertension was similar between groups; however, 52% of participants in the control group had a history of diabetes compared with 28% in the intervention group. On average, participants spent 4 years on dialysis, and 84% of participants were on dialysis at the time of transplant. More participants in the intervention group experienced delayed graft function compared with the control group (27% versus 13%). In the intervention group, 27% had donor-positive, recipient-negative CMV serostatus (high risk) versus 12% in the control group. The 6-month ambulatory procedure history, hospitalization history, and mean number of clinic visits were comparable between groups.

All 68 participants in both arms experienced at least one medication error during the study. There were 904 separate assessments in the 136 participants over the 12-month study (of the 952 potential assessments, 48 were missed; 95% completion rate). In total, there were 1385 medication errors in the control arm (mean 20.4±14.0) and 614 in the intervention arm (mean 9.0±5.9), leading to a 56% reduction in medication errors in the treatment arm. In the multivariable model, total adjusted medication errors were reduced by an average of 0.11 per month in the intervention arm (95% confidence interval [95% CI], 0.05 to 0.17; P<0.001) compared with the control arm, leading to a 61% reduction in the risk rate of medication errors over the 12-month study (incident risk ratio [IRR], 0.39; 95% CI, 0.28 to 0.55; P<0.001). Common administrative errors included omissions, additions, and prescribing errors. Clinical errors were largely due to non- or undertreated conditions, primarily electrolyte abnormalities. Using the Overhage criteria, most medication errors were categorized as significant but ranged from minor to serious.

All study participants in the treatment and control arms reported at least one AE. Rates of grade 1 and grade 2 AEs were comparable between treatment arms. Participants in the intervention arm experienced numerically lower rates of grade 3 AEs, but the difference was not statistically significant (1.10 versus 1.57 per patient-year; P=0.19). The intervention produced significantly lower rates of grade 4 AEs, with an overall 12-month risk reduction of 88% (0.07 versus 0.38 per patient-year, adjusted IRR, 0.12; 95% CI, 0.04 to 0.31; P<0.0001). Participants in the intervention group also experienced a 45% lower incidence risk of composite grade 3 or higher AEs compared with the control group (adjusted IRR, 0.55; 95% CI, 0.30 to 0.99; P=0.05). AEs were most commonly classified as cardiovascular, metabolism, and nutrition disorders or kidney related. The most common cardiovascular AEs were hypertension (n=124) and anemia (n=81). Metabolism and nutrition disorders were primarily electrolyte imbalances, including hypomagnesemia (n=57), hyponatremia (n=41), and hypercalcemia (n=35). Kidney AEs included proteinuria (n=65), elevated creatinine (n=62), CKD (n=49), and hematuria (n=32).

In total, participants receiving the intervention experienced fewer hospitalizations compared with the control arm (44 versus 74). Over the 12-month follow-up, the intervention arm had significantly lower rates of hospitalization (1.08 versus 0.65 hospitalizations per patient-year; P=0.007), with similar rates of clinic visits, procedures, and infections. In multivariable modeling, the intervention produced a 54% reduction in hospitalization compared with control (IRR, 0.46; 95% CI, 0.27 to 0.77; P=0.005). The primary causes of hospitalization were infection, AKI,

and cardiovascular- or gastrointestinal-related conditions. The most common opportunistic infections were BK viremia and CMV.

The impact of the intervention on estimated charges had a lag effect and diverged at 6 months post-randomization. The control arm had a total of $3,272,437 ± $167,154 in estimated charges, leading to an average of $48,124 per patient. Using the 2019 Medicare CCR of 0.266, the estimated total costs of these events in the control arm were $870,468. In the intervention arm, the total estimated charges for hospitalizations were $1,468,005 ± $124,707, or $21,588 per patient; total costs were estimated to be $390,489.

Results from the unadjusted model that compared the charge data in just those with hospitalizations demonstrated a 44% reduction in relative charge risk in the intervention arm versus the control arm (RR 0.56, 95% CI 0.32-0.99; P=.046). After adjusting for DGF, diabetes, and CMV serostatus, the model estimates were similar; the intervention arm had 49% lower charge risk compared with the control arm (RR 0.51, 95% CI 0.28-0.91; P=.022). The unadjusted model demonstrated a 43% reduction in charge risk, which failed to reach statistical significance (RR 0.56, 95% CI 0.31-1.01; P=.053). After adjusting for DGF, diabetes, and CMV serostatus, the estimates were similar but met statistical significance (RR 0.50, 95% CI 0.280.90; P=.022).

During the 12-month study, there were no acute rejections or graft losses in the intervention arm, but there were three rejections (4.4%) and four graft losses (5.9%) in the control arm. There was one death in the control arm, due to ovarian cancer that was likely present and undiagnosed prior to transplant.

The total gross estimated cost savings in the 68 patients randomized to the intervention arm was $479,979 compared with the 68 control arm patients during the 12-month study follow-up period. The total estimated cost to deliver the intervention was $111,140. This included pharmacist time (342 hours estimated to cost $26,744 or $78.20 per hour including salary and benefits); $57,012 to build, maintain, and support the mHealth app and dashboard; $25,709 to purchase smartphones and data plans for participants who lacked an iPhone (n=46); and $1,675 to purchase Bluetooth-enabled blood pressure devices, glucometers, and monitoring supplies for intervention arm participants. The net estimated cost savings for this intervention was $368,839, or $5,424 per patient-year, with an estimated ROI of 4.3.

In this randomized controlled trial, we demonstrated that a pharmacist-led, mobile health–based intervention improved medication safety in kidney transplant recipients. The treatment produced a significant reduction in medication errors, lower rates of grade 3 or higher AEs, and reduced hospitalization rates compared with controls during the 12-month study. In terms of AEs, this study demonstrated a significant difference in severity but was not powered, and it did not demonstrate any difference in type of AEs between the treatment arms.

To our knowledge, this is the first large, randomized, controlled trial demonstrating an improvement in medication safety outcomes in organ transplantation using a mobile health–based technology coupled with a pharmacist-led intervention. One previous study with 108 transplant recipients sought to investigate whether a mobile app targeting nonadherence could improve medication adherence. However, the function of the mobile app was limited to medication alerts and participant education; ultimately, the study did not improve medication adherence. Another study in transplant recipients utilizing the same mobile health platform demonstrated that app users had higher rates of medication recollection, but these findings were not statistically significant. Reese et al. conducted a single-center study to

investigate the effect of using wireless pill bottles to store and record tacrolimus in kidney transplant recipients. Participants were randomized 1:1:1 to adherence monitoring with customized reminders, customized reminders plus provider notification, or wireless bottle use alone. The study demonstrated significant improvement in adherence in each intervention group compared with controls. In a younger kidney transplant population (median age 15.5 years), participants who received the intervention could elect to receive text messages, emails, and/or visual cue medication reminders and met with coaches to discuss adherence data in 3-month intervals. This multicomponent intervention led to significantly better medication adherence compared with controls. McGillicuddy et al. conducted a study to assess the sustainability of improvements in medication adherence after a mobile health–based intervention. A total of 18 participants who completed a 3-month randomized, controlled trial of a mobile health program designed to improve BP and medication adherence were included in this study. Investigators demonstrated that participants in the intervention group continued to exhibit lower BP compared with the control group 12 months after completion of the trial.

In other conditions, several mobile health–based interventions targeting medication safety issues have demonstrated promising results. In one randomized controlled trial involving 411 adults with poorly controlled hypertension, participants randomized to the intervention utilized a smartphone-enabled app that provided medication lists, medication reminders, and BP tracking using a Bluetooth-enabled monitor. The primary outcome measures were change in self-reported medication adherence and systolic BP at 12 weeks. At week 12, participants in the intervention arm demonstrated a small improvement in mean adherence rates compared with control. Other studies have demonstrated improvements in clinical outcomes after a mobile health–based intervention, not necessarily related to medication safety issues.

We designed our study using a pharmacist as the clinician leading the intervention, recognizing that pharmacists are considered medication safety experts. Previous studies have described the benefits of pharmacist-led interventions on medication safety in the transplant population. Musgrave et al. conducted a prospective observational study to determine if transplant pharmacist involvement in transitions of care would improve medication safety. A prospective cohort of 64 abdominal transplant recipients was matched to a historical cohort of 128 patients. During the prospective period, pharmacists prevented 119 out of 191 errors identified on discharge medication reconciliations. In the retrospective cohort, 430 errors were made, and none were prevented at the time of discharge. This study demonstrated a significant reduction in medication errors after transplant pharmacist involvement compared with an historical control. Other studies have described the role of pharmacists during transitions of care outside of the transplant population. One meta-analysis sought to examine the effectiveness of pharmacist-based transitions of care intervention on medication errors after discharge. This study demonstrated that pharmacist involvement in transitions of care leads to a reduction in medication errors and reduces subsequent emergency room visits.

The mobile health app developed by our team and utilized in this study addresses multiple levels of medication safety issues beyond nonadherence and focused on an integrated approach in which a pharmacist served as a clinician-coordinator: identifying potential problems and working with the patient and care team to obtain a mutually agreeable solution. We attempted to address many of the previously identified challenges and goals for mobile health platforms, including interoperability between the EMR and app, developing an effective partnership and buy-in between patients and clinicians, ease of use, and perceived utility to support durable changes, and provide measurable clinically important changes in care. From our results, we believe clinicians should consider integrating these technologies into established clinical treatment pathways to improve medication safety–related outcomes. However, it is

important to recognize that all mobile health–based apps are not created equal. Many existing platforms are narrowly focused on adherence unidirectionally with patients and fail to incorporate clinicians; we believe this inhibits the development of a partnership between patients and clinicians that is a central theory behind the potential effectiveness of mobile health. Future research should focus on comprehensive mobile health apps, such as the one utilized in this study, that investigate a more global approach to medication safety. Furthermore, these apps should appropriately involve healthcare providers, including pharmacists, to adequately mitigate medication safety issues.

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