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Integrating a Mobile App into Pharmacist-Led Patient Education to Enhance Insulin Pen Self-Administration: A Pre-Experimental One-Group Pretest–Posttest Study

Muhammad Thesa Ghozali[1]*, Bagas Dwi Nugroho[1], Anita Agustina Styawan[2], Satibi Satibi[3], Gerhard Fortwengel[4]
[1]School of Pharmacy, Faculty of Medicine and Health Sciences, Universitas Muhammadiyah Yogyakarta, Special Region of Yogyakarta, Indonesia
[2]Department of Pharmacy, Faculty of Health and Technology, Universitas Muhammadiyah Klaten, Central Java, Indonesia
[3]Department of Pharmaceutics, Faculty of Pharmacy, Universitas Gadjah Mada, Special Region of Yogyakarta, Indonesia
[4]Fakultat III, Hochschule Hannover – University of Applied Sciences and Arts, Expo Plaza, Hannover, Lower Saxony, Germany

***Corresponding Author**: E-mail: ghozali@umy.ac.id

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ABSTRACT

Introduction: Objectives This study was conducted to assess the impact of adding mobile health (mHealth) application on pharmacist-mediated patient counseling to improve accuracy of insulin pen self-administration skills among diabetic patients. Introduction Every day, diabetes mellitus (DM) remain one of the worlds biggest health problems where insulins therapy acts among the mainstay in treating type 1 and ineffective treatment for type 2 diabetes mellitus (T2DM). Insulin pens have increased convenience and adherence to insulin therapy compared with traditional vials and syringes; however, administration errors are still prevalent. These errors typically due to incorrect priming, wrong injection angle or failure to discharge air bubbles can lead to hypoglycemia, hyperglycaemia, and loss of glycemic control, with consequent negative impact on therapeutic outcomes. Although the results provide evidence of substantial improvement in dosing accuracy of insulin, causal inference and generalizability are limited by the single-group pretest–posttest design. Controlled studies moving forward are required to validate these results. The goal of this study was to determine if the addition of these mHealth technologies in pharmacist-led education could help us fill this important procedural gap.

Methods: Between December 2023 and May 2024, this study took place in the outpatient clinic of PKU Muhammadiyah Gamping Hospital, Yogyakarta, Indonesia as a pre-experimental, one-group pretest–posttest study. Hundred adult diabetic patients were selected. Structured questionnaires and direct observations based on a standardized insulin pen checklist were used to collect the data. Ethics approval was obtained from Health Research Ethics Committee of PKU Muhammadiyah Gamping Hospital, and all individuals provided written informed consent.

Results: At baseline, 29% of participants achieved high proficiency but post-intervention all (100%) achieved this level. Mean accuracy score significantly improved, from 10.28 (SD = 1.36) to 14.12 (SD = 1.03) ($p < 0.001$). Procedural enhancements were to mix insulin and remove air bubbles.

Conclusion: Pharmacist-led education with mHealth integration, the application of mobile technology in health monitoring, represents a novel and potentially generalisable approach in efforts to improve practices of insulin self-administration.

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INTRODUCTION

Diabetes mellitus (DM) refers to an ongoing and progressive metabolic disease, which is still a great public health problem in the world. Among its treatment options, insulin therapy is essential in type 1 diabetes for glycemic control and often needed in patients with poorly controlled type 2 diabetes mellitus (T2DM). Insulin pens have become in many ways a more catering delivery device than vials and syringes, being more portable (1), user-friendly design (2), patient friendly dose accuracy, and compliance vs the previous era of the vial-and-syringe era (3). international adherence studies report that 30–50% of insulin pen users commit at least one serious error (eg, improper priming, inappropriate injection angle or failure to remove air bubbles). Among insulin-treated patients in a regional cohort of diabetic people, there was at least one major technique error present in 42% and non-adherece to injection best practice among 37% of Indonesian participants (4). Misleading practices result in both suboptimal glycaemic control and preventable clinical complications, yet teachable improvements remain an essential unmet need given the absence of structured education on a standardised technique using insulin pens.

All these issues mentioned above can be managed by tailored education and counseling of on the using insulin pen by pharmacists. It has been demonstrated by several studies in either an inpatient or outpatient setting that pharmacist-led training decreases administration errors and consequently increases patient safety (5,6). A 30% reduction in incorrect dosing with insulin pen was demonstrated after pharmacist-facilitated teaching of elderly patients in a large multicenter study conducted in Saudi Arabia (7). However, most of today interventions are guided at a centrally organized one-time training event and they do not reflect the required consistency and elaboration needed for sustainment over time.

The absence of prolonged follow-up results in an important void in diabetes patient education, especially for the high-risk population such as elderly individuals, patients with low health literacy, or residents in rural areas (8,9). Mobile health (mHealth) technologies have the potential to fill this gap by delivering accessible and continuous support. Delivery of reminders, interactive content and real-time feedback are believed to enhance diabetes self-care, medication adherence level and glycaemic control (10,11), thereby digital applications have shown their efficacy in improving diabetes outcomes. However, there were only a very limited number of studies that have investigated the potential incorporation of such technologies with regards to enhancing insulin pen technique in a pharmacist-education context.

This is an important gap in the literature. Although some mobile applications have been tested in the general context of diabetes management or glucose monitoring (12), very few addressed the procedural details needed for insulin pen administration including recommended storage, pen priming, injection angle and time after injection based on experimentally validated checklists. While visual and multimedia techniques are effective for teaching injection techniques (13,14), evidence relating to the delivery of these methods through a mobile app context specifically in insulin administration is still limited. In addition, advances in the technique utilized by patients confer downstream clinical and economic advantages. Healthcare institutions have reported reduction in insulin pen wastage and associated costs post-structured pharmacist and nurse-led training implementation (15). Similar clinical and technical benefits of counselling have also been reported in the insulin dependent population with community pharmacists using on-site rotation practices following counselling (16).

This study is theoretically grounded in existing behavior models, primarily the Health Belief Model (HBM) and Social Cognitive Theory (SCT). According to the HBM, a person's decision on whether to comply with the recommended technique for insulin pens are influenced by their own perceived risk of complications, their perceptions about the benefits and correct dosing and self-efficacy for performing behavior. This is supported in the mobile app element, which provides always-available education content and regular nudges to action. Then, SCT stresses that observational learning (the action of observing and imitating a behavior), reinforcement, and self-regulation actually take place using the app's video models, reminders, and interactivity. Together, these frameworks inform the theoretical explanation for how this intervention results in sustainable behavioral change specifically in insulin self-administration.

Against this backdrop, assessing mHealth solutions delivery as part of pharmacist-led insulin education programs is needed. The combined effect of clinical pharmacy knowledge and digital reinforcement may provide a new scalable solution to optimize the use of insulin pens in order to directly improve patient outcomes. Thus, this study aims to evaluate the impact of mobile application (within a pharmacist-led educational intervention) on competency and standardisation of insulin pen self-administering.

METHOD

Research Design and Participant

This study used a quantitative pre-experimental one-group pretest–posttest design to evaluate the effectiveness of mHealth app–assisted patient educational intervention on the accuracy of insulin pen administration in patients with diabetes mellitus. The research was carried out at the outpatient department of PKU Muhammadiyah Gamping Hospital, the Special Region of Yogyakarta, Indonesia. Data collection for the study was conducted in a period from December 2023 to May 2024. The study design above did not have a control group (between-group) but allowed evaluation of possible within-group changes due to the intervention.

Study population All adult patients (≥18 years) diagnosed with diabetes mellitus and currently undergoing treatment (insulin therapy). Eligible participants were current insulin pen users or those willing to start using an insulin pen. Other inclusion criteria mainly comprised of: (1) a diagnosed case of diabetes mellitus, (2) consent for use with an insulin pen, and (3) access to a smartphone qualified with the educational mobile app. Exclusion criteria were as follows: (1) cognitive impairments that would prevent an individual from following app-based directions, (2) received standardised diabetes education in the previous 6 months and (3) severe visual or motor impairments preventing easy use of mobile phone or insulin pen.

As for the recruitment and sampling, a mix of digital and on-site outreach strategies were used to recruit participants. This included announcements and informational materials shared via social media (WhatsApp group, Facebook, and Instagram), direct messaging, personal networks and in-person patients/presentations in the hospital outpatient clinic. Sample size estimation was carried out applying the Lemeshow and Lwanga formula that is appropriate for pretest–posttest design providing sufficient statistical power to observe significant differences between pre- and post-intervention measures.

This pre-experimental one-group pretest–posttest design was selected as an early exploratory design to provide initial evidence of intervention effectiveness before conducting larger randomized trials. The design facilitated within-subject comparisons of pre- and post-intervention performance, which is well suited for educational interventions as participants serve as their own control. The lack of a comparator group was an a priori methodological decision, based on ethical and logistical grounds, withholding pharmacist-taught education from eligible patients with diabetes in clinical care settings going against long-prized tenets of patient-centredness. Furthermore, the main goal was to provide preliminary data that can be used for planning future controlled long term follow up studies.

Research Instruments

This study intervention consisted of an mHealth-based educational program through a mobile application called "Diary Diabetes"(Figure 1) specifically designed to promote precision insulin pen administration in diabetes patients. The app also featured thousands of video-based instructional content organized in bite-size, interactive formats to foster learning and voracious usage. Important aspects of the education content included: visual and verbal demonstration of correct injection technique, dose setting, preparation of the pen, site rotation and other procedures important for insulin pen handling. The technical development of all teaching videos was performed according to PERKENI clinical guidelines and is appropriately designed to establish contextual relevance. The participants downloaded the app on their personal phones which allowed them to carry it around and access the resources whenever they needed. Features that support learning and adherence included interactive components of the app, such as push notifications and reminders. Participants received daily reminders to use the app and usage data logs were monitored regularly to assess participant compliance with intervention protocols.

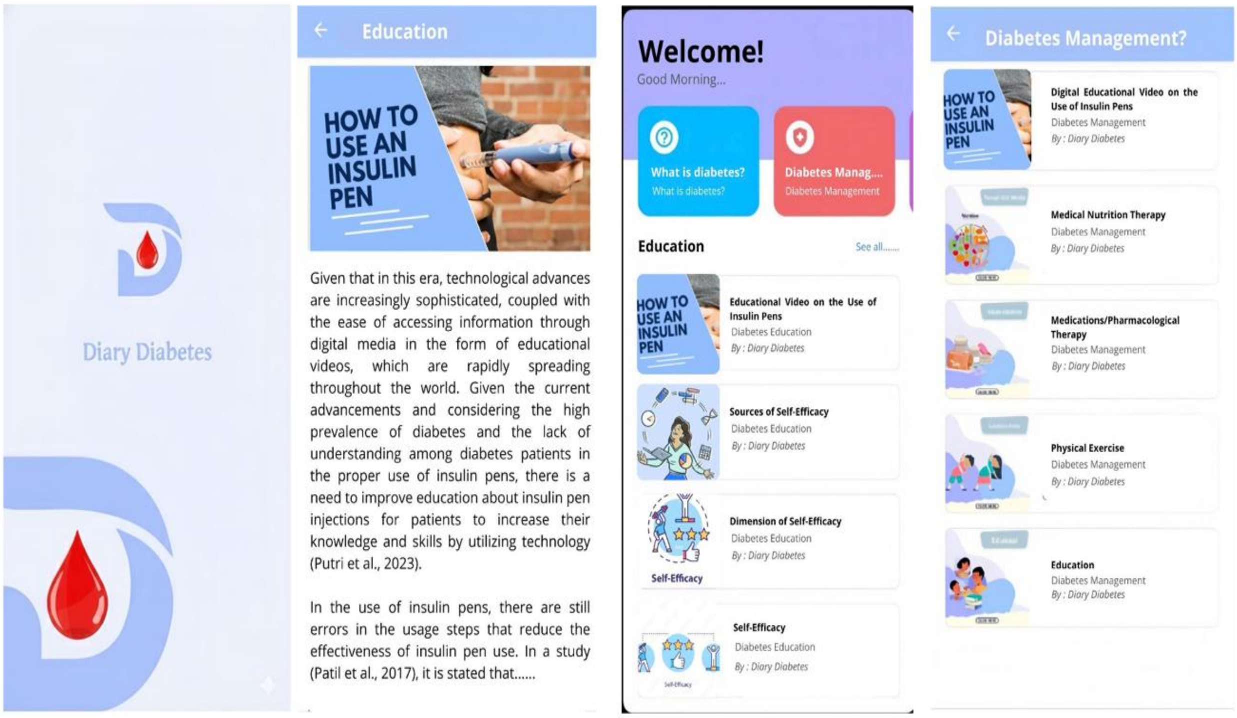

Figure 1. Screenshots of the Diary Diabetes App User Interface

Features of the Diary Diabetes mobile application that was developed for this study. Panel (A) is the home dashboard, which includes all instructional modules for insulin pen preparation, injection technique and storage instructions. Interactive video tutorial page (Panel (B)), with pharmacist endorsed examples of the video clips, replay and navigate all options. Panel (C) shows the reminder and notification user interface used to encourage daily usage of insulin and also using through app. The interface was created in locally referenced languages to make the app culturally and linguistically appropriate—for example, Bahasa Indonesia among other available locales.

Educational content was tailored to the characteristics of insulin pen devices that are most commonly prescribed in Indonesia. The materials identified standard pen components (eg, dialable dose selectors, removable caps and attachable disposable needles). While the app was not manufacturer-specific, instructional information was developed to be applicable for each of the major types of insulin pens available in that area (Novo Nordisk and Sanofi). To evaluate real-world relevance, the study participants were directed to identify and confirm their own prescribed insulin pens. This increased the external validity of the findings as it made the app-based guidance generalizable to pen devices outside of that used in testing.

Over the study period, all participants were instructed to self-administer their insulin injections. An assessment of whether or not the participant could self-administer insulin without assistance was completed before the beginning of intervention for verification of use (to determine if they could administer using the pen properly alone). If the patient received continuous insulin treatment and treatment was usually performed by a caregiver, the caregiver was enrolled in the educational intervention arm and educated simultaneously with his or her patient. We captured the mode of administration—administered by self or caregiver—to reduce inter-subject variability in outcome for each subject.

Intervention

Intervention consisted of an mHealth via mobile application, the 'Diary Diabetes' educational program that was intended to optimize insulin pen delivery precision. The program included five consecutive teaching modules, each with ~2–3 min videos. The video content was compiled in sequential order: preparing, to priming, to dialling insulin doses and the injection technique (site rotation) plus post-injection procedures (Figure 2). Participants all completed the five modules in order before doing the post intervention assessment, and usage analytics from the app were used to confirm engagement. A threshold of 80% of total instructional content viewed (twelve plus minutes of combined viewed time) was established as indicative of minimum engagement, a threshold met by all study participants included in final analysis. The schematic work-around introduced a series of videos to build upon the continuity of learning and mastery of procedure and wrapped them up in short visual steps at every stage so that learners stayed engaged.

Data Collection

Questionnaires were created following the guides of the European Association for the Study of Diabetes (EASD) (17). to collect data. It was a questionnaire covering several aspects of insulin pen usage including user knowledge, technical proficiency and adherence to best practice principles governed by the respective manufacturers regarding both injection techniques. The instrument was administered twice in two time points: (1) baseline, before the educational intervention; and (2) post-test, after the mobile app-assisted training. Baseline data was collected to establish each participant's preintervention ability to use insulin pens, whilst postintervention data evaluated the difference in performance due to the intervention. A structured checklist adapted from previously validated instruments (17). was used to assess accuracy of insulin pen use. Included in the checklist were items assessing correct dosing, injection sites, pen priming and post-injection procedures. Standardised assessments were performed by a registered pharmacist who was trained in techniques of insulin administration.

Data Analysis

All statistical analyses were performed using IBM SPSS Statistics version 26.0 (IBM Corporation, Armonk, NY). Demographic characteristics and baseline data of the participants were characterized using summary statistics. A Wilcoxon signed-rank test was conducted to assess the changes in insulin pen utilisation before/after the intervention as data are paired and not normally distributed. The specific definition of statistical significance was $p < 0.05$. This design provided a conservative measure of the effect, or lack thereof, of app-assisted learning on the performance of participants in any manner performing subcutaneous injection with an insulin pen.

Ethical Approval

Ethical approval was obtained from the Ethics Committee of Health Research (KEPK), Education and Training Division, PKU Muhammadiyah Gamping Hospital, Yogyakarta Indonesia with a reference number KEPPK 158/ KEP-PKU / IX/2023. All study participants provided written informed consent prior to enrolment. All participation was voluntary in nature and during the course of research personal data were kept private.

RESULTS

Participant Characteristics

A total of 118 eligible patients were approached during the recruitment period, and 100 consented to submission (participation rate = 84·7%). Eighteen (15.3%) declined, mainly due to time or lack of comfort with smartphone apps; According to clinical records, participants and non-participants were not different in age, sex or duration of diabetes. These findings suggest that the final sample was overall representative of diabetic patients using insulin who were referred to outpatient clinic, hence minimizing the risk of a selection bias advantage.

This research included 100 cases of diabetic patients, and all the surveyed people had previously been selected based on the eligibility criteria. Table 1 below includes participants demographic characteristics from the study. Participants aged 40–60 years (n = 55; 55.0%) were the most common, followed by those aged 18-39 (n = 25; 25.0%) or over age of ≥61, (20; %). Of which males were 48 (48·0%) and females were 52 (52·0%), so the male-to-female ratio is roughly balanced. Educational background: 45 education participants (45.0%) completed high school, and 25 (25.0%) achieved higher education. The majority of the participants had diabetes for >5 years, including 50 (50.0%) for 5–10 years and 20 (20.0%) at >10 years duration. Seventy-one participants (71.0%) were determined to have competent ability in the use of insulin pens at baseline; 29 (29.0%) demonstrated high competence level.

Table 1. Demographic Characteristics of Study Participants (N = 100)

Demographic Information	N (%)
Age (years old)	
a) 18 – 39	25 (25.0)
b) 40 – 60	55 (55.0)
c) > 60	20 (20.0)
Gender	
a) Male	48 (48.0)
b) Female	52 (52.0)
Educational Level	
a) No formal education	10 (10.0)
b) Primary education	20 (20.0)
c) High school education	45 (45.0)
d) Higher education	25 (25.0)
Duration of Diabetes (years old)	
a) <5 years	30 (30.0)
b) 5-10 years	50 (50.0)
c) >10 years	20 (20.0)
Level of Proficiency	
a) Low	0 (0.0)
b) Sufficient	71 (71.0)
c) High	29 (29.0)

Effectiveness of the Intervention

The results from pretest and posttest comparison showed large improvements in accuracy of insulin pen use after mobile app-assisted educational intervention. Before the intervention, no participants had very high proficiency, while 29% demonstrated total mastery; afterwards, all (100%) had achieved total mastery. As shown in Table 2 below, there were significant increases in certain procedural steps. For example, following important safety steps such as "rolling cloudy insulin until mixed and not separating different types of insulins" (8% vs 92%), "removing air bubbles immediately prior to injection" (11% vs 89%), and resetting dose to zero before drawing up the next dose (11% versus 89%) significantly improved from baseline.

Table 2. Stepwise Accuracy in Insulin Pen Use Before and After Intervention (N = 100)

No	Steps on Insulin Pen Use	Before (N)	After (N)
1	Remove pen cap	100 (100.0)	100 (100.0)
2	Roll cloudy insulin pen until uniformly mixed	8 (8.0)	92 (92.0)
3	Attach new needle	100 (100.0)	100 (100.0)
4	Remove outer needle cap	100 (100.0)	100 (100.0)
5	Dial dose to 2 units	11 (11.0)	89 (89.0)
6	Remove air bubbles	11 (11.0)	89 (89.0)
7	Reset dose to zero	11 (11.0)	89 (89.0)
8	Dial prescribed dose	100 (100.0)	100 (100.0)
9	Inject at 90-degree angle	100 (100.0)	100 (100.0)
10	Press injection button slowly to zero	100 (100.0)	100 (100.0)
11	Hold for 6 – 10 seconds	100 (100.0)	100 (100.0)
12	Withdraw needle	100 (100.0)	100 (100.0)
13	Replace needle cap	100 (100.0)	100 (100.0)
14	Remove needle	48 (48.0)	52 (52.0)
15	Replace pen cap	100 (100.0)	100 (100.0)

While the overall post-intervention competence remained in the classification of 'high,' some procedural steps—especially, needle removal—showed small percentage changes (48% vs 52%). American added that this mirrors the relatively low weighting of this step in what was ultimately a 15-item accuracy checklist, with thresholds for scoring determined by cumulative performance rather than isolated task completion. Within this framework, participants achieving ≥90% of total available points were designated a 'high proficiency' although performed some steps with minor inconsistencies. This marginal improvement in needle removal probably reflects entrenched behaviour, namely the use of disposable pen needles for reuse to save money, which is also common among insulin pen users from low- and middle-income settings. However, this represents a minor mark against the overall procedural safety or accuracy—every other key step from priming to dose adjustment to air bubble removal showed near-universal improvement post-intervention.

Descriptive Statistics and Proficiency Shift

The results in terms of mean accuracy scores were distinctly improved, as displayed by the descriptive statistics. The pretest score average was 10.28 (SD = 1.36), while the posttest average increased to 14.12 (SD = 1.03). Score ranges improved, moving from a pretest maximum and minimum of 8–14 to posttest scores of 11–15 also indicating that the consistency in pen use technique or mastery has greatly improved.

Table 3. Descriptive Statistics of Pretest and Posttest Scores (N = 100)

Test	N	Mean*	Min	Max	SD
Pretest	100	10.28	8	14	1.36
Posttest	100	14.12	11	15	1.03

*The mean value represents the average aggregated score for insulin pen use accuracy across all participants

Statistical Analysis

Table 4 shows that compared to the pre-Test, proficiency levels reported a total switch towards high proficiency after the intervention. The Shapiro–Wilk test for normality demonstrated that these pretest and posttest data were not normally distributed ($p < 0.001$), therefore non-parametric statistical tests could be used. Statistically significant improvement from pretest to posttest scores, as measured by the Wilcoxon signed-rank test (Asymp. Sig. = 0.00), indicating that the app-assisted intervention improved accuracy in use of an insulin pen. In addition to statistical significance, the effect size for the Wilcoxon signed-rank test was calculated using the formula $r = \frac{Z}{\sqrt{N}}$, yielding a value of 0.82. According to Cohen's criteria, this represents a large effect size, suggesting that the mHealth-assisted educational intervention produced a substantial practical impact on improving insulin pen administration accuracy. The magnitude of this effect reinforces the meaningfulness of the observed improvements beyond statistical significance ($p < 0.001$).

Table 4. Summary of Proficiency Levels, Normality Test, and Wilcoxon Test Results

Summaries	Parameters	
Proficiency Levels	**Pretest**	**Posttest**
a) Low	0 (0.0)	0 (0.0)
b) Sufficient	71 (71.0)	0 (0.0)
c) High	29 (29.0)	100 (100.0)
Normality Test	**Sig.**	**Interpretation**
a) Pretest	0.000	Non-normal Distribution
b) Posttest	0.000	Non-normal Distribution
Wilcoxon Test		
Asymp. sig. (2-tailed)		0.000

DISCUSSION

Interpretation of Results

A mobile health (mHealth) app-assisted educational intervention significantly increased the accuracy of insulin pen use among patients with diabetes. The percentage of participants achieving high proficiency improved significantly from baseline (29.0%) to post-intervention (100.0%). In addition, the mean accuracy score increased from 10.28 (SD = 1.36) to 14.12 (SD = 1.03), indicating a significant gain in performance on all assessed procedural steps (all N = 15). This data supports the research hypothesis that we can reduce knowledge and skill gaps in insulin self-administration using technology-enhanced educational approaches. Although better procedural accuracy is anticipated to enhance the clinical management of diabetes, we did not directly measure HbA1c levels, hypoglycemic events or insulin utilization efficiency in this study. Thus, any inferred relationship between clinical downstream outcomes would be speculative and need to be validated in longitudinal or controlled future studies. Current evidence however supports strong evidence of improved technical skill and compliance, key behavioural precursor to better clinical outcomes. This is especially concerning considering the clinical risks of poor insulin usage, including glycemic instability; non-adherence to treatment: and even hospitalisation for hypoglycaemic or hyperglycaemic events (18,19). The fact that this intervention can remedy problems with the procedure and particularly steps performed poorly—and thus, in principle, not just be an exercise in theory but actually lead to procedural learning–demonstrates its practical relevance.

Improving Technique Through Interactive mHealth Learning

Most noticeable enhancement was seen in less commonly acknowledged steps including insulin mixing, air bubble removal and reset of the dose. Before the intervention, only 8 to 11% of participants successfully completed these tasks, but afterwards that number grew to more than 89%. This is consistent with previous research demonstrating that procedural errors often result from a lack of visual presentation and reinforcement during typical clinical training (20,21). Implementation of a validated checklist within the app led to focused learning and self-assessment, consistent with principles of educational best practice that underscore active engagement and repetition (22). Relative to static pamphlets or one-off demonstrations, the app's multimedia format and interactive reminders created an ongoing interactive learning space that reinforced long-term skill retention (23).

Combined, these findings support earlier research demonstrating that mHealth self-management interventions improve chronic disease management via personalized, continuous, and as-needed educational materials (24–26). Digitial interventions, unlike traditional models, can provide opportunities for patients to self-pace their learning experience and revisit important concepts as needed, being beneficial to even diverse learning styles. In addition, the growing digital literacy in semi-urban and rural populations is making mobile solutions for patient education much more scalable (27,28).

Comparison with Existing Educational Models

In comparison, this digital approach offers significant advantages compared with traditional diabetes self-management education (DSME), which often leads to improved knowledge but little change in procedural habits (29). Time does not exist in homogeneous forms and every educator has thier on style of imparting knowledge leading to inconsistency in traditional education and no standardisation. On the other hand, all participants received information of uniformly high quality from the app, regardless of demography. Importantly, high rates of proficiency post-intervention achieved across participant group definitions furthers the notion that this app is effective regardless of age, education level and/or disease duration. The results are corroborated with findings in other fields, eg, that app-based interventions improved patient self-care behaviours in asthma and chronic pain managemen (30,31).

Novelty and Contribution

Previous studies of digital health interventions for diabetes education focused on general glycemic control, medication adherence or lifestyle modification; however, this study targeted the unique and procedural component of insulin pen administration accuracy a known gap in many existing digital health studies. This intervention differs from historical mHealth tools in that it integrates pharmacist-led education with an entertaining and culturally-adapted mobile application designed for the Indonesian healthcare system. Besides higher-level education, the Diary Diabetes app includes visual demonstrations, interactivereinforcement cues and stepwise assessment of technique using a standardized clinical checklist. This in turn is distinct from previous app-based studies that mainly focus on changing knowledge, rather than proficiency because this multi-dimensional design simultaneously integrates a variety of educational domains (cognition and psychomotor).

Practical and Clinical Implications

Such findings are thus of relevant pragmatic implications. Good technique with an insulin pen should lead to better glycaemic control, less wasted insulin and fall in the complications of treatment. At a health system level, mHealth interventions can ease the burden on health care providers through more uniform and accessible education tools that supplement clinical counseling. The Diary Diabetes app offers use in routine care delivery, both reinforcing knowledge of the state of disease and building self-efficacy supported by pharmacists and diabetes educators, as well as enabling caregivers to facilitate independent insulin administration in those they support. These findings underpin international calls to integrate digital therapeutics into broad public health systems for non-communicable disease management, especially in low-and-middle income countries where access to specialist care remains limited (32).

Strengths and Limitations of the Study

The strengths of this study are related to methodology and can be summarized as follows. The evaluation utilized an appropriately powered sample size (N = 100), a validated 15-item checklist for the assessment, and independent by trained pharmacists. The pretest–posttest design allowed for comparisons within the same individuals, reducing variability. Lastly, the clinical relevance of the educational intervention was ensured by national PERKENI guidelines for educational content, and supplementing pen reminders with most brands of insulin pens enabled generalizability conclusions. Including caregivers where appropriate increased the ecological validity of this study considerably. Once it was clear that the data distribution is not normal, reinforcement of the analysis with appropriate non-parametric statistical methods only made it more robust.

Nevertheless, some limitations deserve to be acknowledged. The absence of a control group was a crucial methodological limitation of this study, making it impossible for us to conclude that mobile app assisted intervention caused also improvement in accuracy on insulin administration. Even without a comparison group, any improvements may confound an effect of the intervention with repeated exposure to evaluation or becoming increasingly familiar with the criteria stated in checklists. Thus, these findings should be interpreted as in their early stages of efficacy with no causal proof. In addition, the single-center design and the characteristics of our region sample limits external validity in other health care settings or cultural environments. Causality and external validity would benefit from randomized controlled style and multisite sampling in future studies.

Moreover, the relatively brief follow-up period restricted assessments of durability or clinical measures such as HbA1c changes. Although participants were instructed to use the app, application usage (e.g., amount of apps used and videos completed) were not recorded in detail and, thus exploration of the link between exposure to the app and improvements is limited. Recruitment also favoured motivated, tech saturated individuals; thus, there was continuing self-selection bias. Finally, even though we recorded caregiver involvement and self-administration versus caregiver-assisted administration, stratified analyses were not performed and should be addressed in the future.

Directions for Future Research

These findings highlight the double benefit of skills-based education and interactive technology. Future studies should incorporate randomised controlled designs with longer follow-up for sustainability of improvements and examination of clinical endpoints through change in HbA1c. Quantitative data around APP usage metrics may help capture possible dose-response implications. In addition, study outcomes must be stratified by whether or not subjects aided another and explore potential changes to the app for other self-administration routes of delivery such as GLP-1 receptor agonists or other injectable medications. This would promote scalability of this intervention, which could be improved even more by investigating its use in different populations (e.g. low-literacy, rural) for greater generalizability.

CONCLUSION

This research demonstrates mobile app-assisted education may improve insulin pen technique in patients with diabetes mellitus. The intervention reduced the gap from knowledge to practice by leveraging the availability, interactivity and personalization afforded by mobile health technologies. The results demonstrate the capacity of evidence-based mHealth tools to provide scalable and patient-centered approaches to address self-care behaviors intrinsic in modern diabetes management. Such interventions may increase empowerment for patients living with diabetes, optimise clinical outcomes and could potentially advance integration in discontinuous models of diabetes care as digital health platforms iterate over time, augmenting existing types of diabetes education.

AUTHOR'S CONTRIBUTION STATEMENT

Muhammad Thesa Ghozali: Conceptualization; Methodology; Supervision; Project administration; Writing – original draft; Writing – review and editing. Bagas Dwi Nugroho: Investigation; Data curation; Formal analysis; Visualization; Writing – original draft. Anita Agustina Styawan: Methodology; Validation; Writing – review and editing. Satibi: Validation; Supervision; Resources; Writing – review and editing. Gerhard Fortwengel: Supervision; Critical review of the manuscript; Writing – review and editing. All authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest relevant to the content of this study.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this manuscript, the authors used DeepL (for translation assistance) and Grammarly (for grammar and language refinement) to support the writing process. The authors critically reviewed, edited, and approved the final version of the manuscript. The intellectual content, scientific interpretation, and conclusions are entirely the work of the authors.

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