Review Article

# Effectiveness of Smartphone-Based Interventions on Medication Adherence in Type 2 Diabetes Mellitus: A Systematic Review

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## Abstract

Medication non-adherence in patients with type 2 diabetes mellitus (T2DM) is a major contributor to poor glycaemic control and diabetes-related complications. Mobile applications offer a promising strategy to support adherence, yet evidence of their effectiveness remains limited. This systematic review examines the impact of mobile app interventions on medication adherence among adults with T2DM. A systematic search was conducted in PubMed, Cochrane Library, and Scopus databases. English-language studies published between 2013 and 2023 were included. Study quality was evaluated using the Mixed Methods Appraisal Tool. Seven clinical studies, comprising 717 participants (median age, 54.7 years), met the inclusion criteria. All studies reported improvements in medication adherence, although only four demonstrated statistically significant effects. Of these, three studies also observed significant reductions in HbA1c levels, indicating potential clinical benefit. Overall, study quality was generally high. Mobile applications show potential in enhancing medication adherence in adults with T2DM compared to standard care. However, the features driving these improvements remain unclear due to heterogeneity in study design and limited sample sizes. Future research should aim to identify key app components, optimize usability, and evaluate cost-effectiveness to maximize clinical outcomes.

**Keywords:** Medication adherence, Type 2 diabetes mellitus, Mobile health, Digital interventions, Systematic review

## Introduction

Diabetes mellitus (DM) poses a significant worldwide health issue, with its incidence steadily on the rise. As of 2019, approximately 460 million people were affected by DM, a figure expected to climb to 629 million by 2045. Effective management of type 2 diabetes mellitus (T2DM) requires a multifaceted approach, encompassing lifestyle modifications, pharmacological treatments, regular self-monitoring, and ongoing medical support. Nevertheless, the intricate nature of T2DM care frequently results in suboptimal medication compliance, exacerbated by the development of secondary health issues [1-4]. Inadequate adherence to prescribed medications contributes to suboptimal blood sugar regulation and an elevated risk of related complications [5-9].

As a form of telemedicine, mobile applications provide diverse engaging tools like alerts, informational resources, and virtual consultations, designed to boost compliance in individuals with chronic conditions, such as those with T2DM.– That said, the actual impact of these tools on enhancing medication adherence in T2DM patients is still inconclusive, which has limited their widespread adoption in diabetes care [10-17]. Therefore, this research aims to evaluate the effectiveness of mobile applications in promoting better medication adherence among T2DM patients.

## Materials and Methods

### *Study Selection Criteria*

The inclusion criteria for the literature search targeted English-language publications examining the impact of mobile applications on medication adherence in adult patients diagnosed with type 2 diabetes mellitus. This systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. The specific inclusion and exclusion standards

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applied during the article screening process are summarized in **Table 1**.

**Table 1.** Inclusion and exclusion criteria

| Inclusion criteria | Exclusion criteria |
|---|---|
| **1. Studies evaluating the effectiveness of mobile application interventions on medication adherence in patients with T2DM** | 1. Studies involving other forms of telemedicine interventions |
| **2. Adult patients (≥ 18 years) diagnosed with T2DM** | 2. Studies focusing on adherence to self-monitoring, diet, exercise, clinical guidelines, lifestyle modifications, or general clinical care |
| **3. Articles published in English** | |
| **4. Published between 2013 and 2023** | |
| **5. Full-text articles accessible** | |

T2DM = type 2 diabetes mellitus.

### Search Strategy

We conducted a comprehensive systematic search across PubMed, Scopus, and the Cochrane Library to identify pertinent studies published between 2013 and 2023. Our literature retrieval employed a combination of subject headings and expansive keyword approaches to achieve thorough inclusion of available evidence. The search protocol was crafted to address three primary areas: medication adherence, diabetes management, and telemedicine applications **(Table 2)**. For optimal retrieval, the three core domains were linked via the Boolean operator 'AND', whereas terms within each domain were combined using the Boolean operator 'OR'.

**Table 2.** Literature review search strategy

| Adherence | Diabetes | Telemedicine/Mobile health |
|---|---|---|
| **Adherence** | Diabetes | Telemedicine |
| **Non-adherence** | Type 2 diabetes mellitus | Telehealth |
| **Non-adherence** | Type II diabetes mellitus | Telepharmacy |
| **Compliance** | T2DM | mHealth |
| **Non-compliance** | Hyperglycemia/Hyperglycaemia | eHealth |
| **Non-compliance** | Glucose intolerance | Mobile application/Mobile applications |
| | | Mobile apps |

### Study Selection

All retrieved citations from the search were transferred into Mendeley Cite (Elsevier Limited, London, UK), where automated features were applied to eliminate duplicates. Two independent authors reviewed titles and abstracts in relation to the inclusion and exclusion standards detailed in **Table 2**. Any studies failing to align with these standards were discarded during this phase. Subsequently, the complete texts of articles deemed potentially suitable were obtained and examined. Suitability was reevaluated using a standardized checklist, with articles categorized as included, excluded, or pending additional review. For studies marked as pending, in-depth deliberations occurred among the authors, culminating in unanimous decisions on final inclusion.

### Data Extraction and Management

Once eligibility was verified, two authors (AR and HN) separately gathered data from the selected studies. The compiled details encompassed key study attributes, including participant numbers, research environment, methodology, mobile app designation, average participant age, sex composition, intervention length, and demographic profiles. Additionally, outcome-related information was documented, covering comparison groups, application features, and documented influences on medication compliance, along with pertinent clinical results. To gauge potential bias, evaluations were conducted using procedural standards and tailored study elements, thereby facilitating robust assessments of the overall study credibility.

### Quality Assessment

Methodological rigor was assessed using the Mixed Methods Appraisal Tool (MMAT) Version 2018, which supports evaluations across diverse research formats, including qualitative inquiries, randomized controlled trials, non-randomized approaches, quantitative descriptive analyses, and mixed-methods designs. For each study, five specific methodological domains were reviewed, yielding ratings of Yes (fully satisfied), No (not satisfied), or Unclear (lacking details). Based on the count of satisfied domains, studies were rated as low quality (≤ 2 met), moderate quality (3 met), or high quality (≥ 4 met).

## Results and Discussion

The study identification procedure is depicted in the PRISMA flowchart **(Figure 1)**. The preliminary search generated 1,205 articles, reduced to 946 following the removal of duplicates. Title and abstract screening resulted in the rejection of 919 articles, prompting the retrieval of complete texts for the 27 remaining ones (with one full text being unavailable). Ultimately, seven studies met all the inclusion requirements.

Primary exclusion rationales involved investigations that overlooked medication adherence, those targeting unspecified chronic conditions, or ambiguities concerning the specific diabetes variant under study. Additional insights into exclusions across phases are illustrated in **Figure 1**.

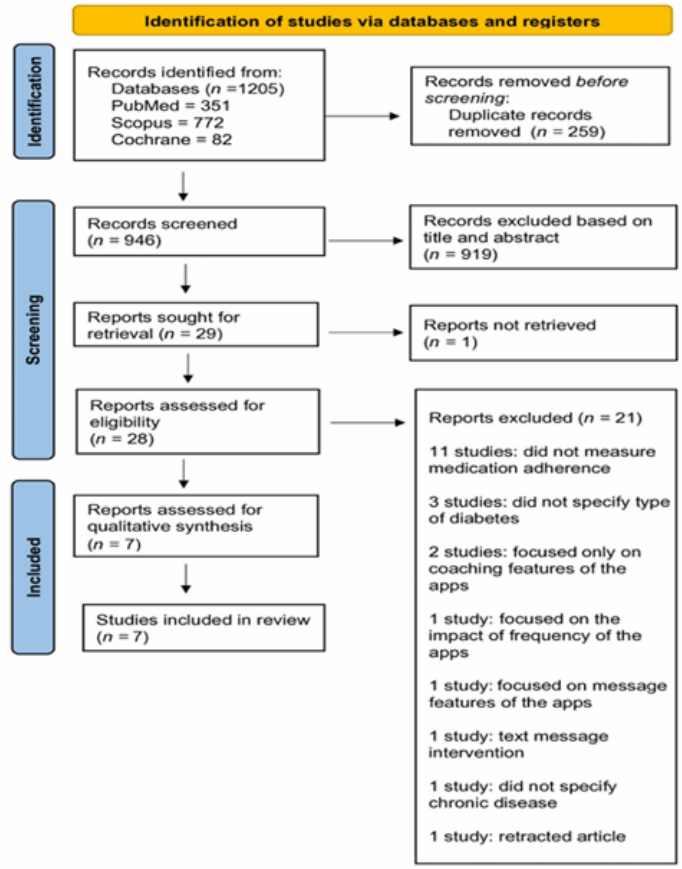


**Figure 1.** PRISMA flow chart.

## Characteristics of Included Studies

**Table 3** summarizes findings from seven investigations involving a combined total of 717 subjects. The median participant count per study stood at 93.5, with sizes varying between 17 and 220. Participants' ages ranged from 48 to 64 years, with a median of 55 years. The proportion of female participants fluctuated between 30% and 55%, averaging 44% overall. Every study focused exclusively on adult individuals of both sexes diagnosed with T2DM. The rate of participants with higher education (college level or above) differed from 5% to 69%, although two investigations omitted details on educational backgrounds. The chosen articles were divided into two categories: those that examined only the influence of mobile apps on medication compliance, and others that evaluated both compliance and a clinical endpoint. Further information on the results of these investigations is presented in **Table 4**.

**Table 3.** General characteristics of included studies and participants

| Study | Year | Country | Mobile app | Study design | Sample size | Mean age (years) | Female (%) | Duration | Participants characteristics | Education level (≥ college %) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Kleinman *et al.* [18]** | 2017 | India | Gather Health | RCT | IG = 44<br>CG = 46 | IG = 48.8<br>CG = 48.0 | 30.0 | 6 months | Patients diagnosed with T2DM for > 6 months, A1c of 7.5%–12.5% at diabetes-focused clinics in India | 26 |
| **Kjos *et al.* [19]** | 2019 | USA | Medsimple | Prospective, observational, single-cohort study | 51 | 52.3 | 54.9 | 6 months | Adult patients living in communities with T2DM in the USA who are taking a minimum of 2 prescribed medications | 69 |
| **Huang *et al.* [20]** | 2019 | Singapore | Medisafe | RCT | IG = 22<br>CG = 19 | IG = 51.5<br>CG = 52.0 | 51.2 | 12 weeks | Patients diagnosed with T2DM, aged ≥ 21 years old, on insulin or oral hypoglycaemic agents, and English speakers | 59 |
| **Chao *et al.* [21]** | 2019 | Taiwan | IPMF | Experimental design and RCT | IG = 49<br>CG = 48 | 63.1 | 39.0 | 2 years | Patients diagnosed with T2DM within the prior 3 months, HbA1c ≥ | 5 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 5.4%, oral glucose tolerance test results > 140 mg/dL | |
| **Yang *et al.* [17]** | 2020 | Korea | Hicare Smart K | RCT | IG = 150 CG = 70 | IG = 54.1 CG = 60.6 | 49.4 | 3 months | Outpatients attending primary care clinics diagnosed with T2DM and having HbA1c levels ranging from 7%–10% (53–86 mmol/mol) | ns |
| **Batch *et al.* [16]** | 2021 | USA | Time2Focus | Pilot study | IG = 100 CG = 101 | 57.3 | 49.8 | 12 weeks | Patients diagnosed with T2DM, HbA1c ≥ 8% and < 12% in the past 3 months at a primary care clinic in North Carolina | ns |
| **Orozco-Beltrán *et al.* [22]** | 2022 | Spain | DeMpower | Ambispective Study | IG = 11 CG = 6 | IG = 63.3 CG = 64.4 | 34.0 | 52 weeks | Patients with HbA1c levels ranging from ≥ 7.5% to ≤ 9.5%, who were undergoing treatment with non-insulin antihyperglycaemic agents, and were being treated at healthcare facilities in Spain | 26 |

A1c = haemoglobin A1c; CG = control group; HbA1c = haemoglobin A1c; IG = intervention group; IPMF = interactive personalised management framework; ns = not stated; RCT = randomised controlled trial; T2DM = type 2 diabetes mellitus; and USA = United States of America.

**Table 4.** Outcomes of the studies using measures of adherence.

| Study | Control group (CG) | App functions | Relevant outcome | Adherence measure | Clinical outcome measure |
|---|---|---|---|---|---|
| **Kleinman *et al.* [18]** | Usual care | Medication reminders, data collection and visualization, blood glucose test reminders, behavioral assessment, collaborative care decision | Self-reported medication adherence | Mean adherence IG = 39.0%, CG = 12.8% (P = 0.03) | Reduction in HbA1c levels IG = 1.5%, CG = 0.8% (P = 0.03) |
| **Kjos *et al.* [19]** | Pre-intervention assessment | Behavior change technology, action planning, prompts/cues, self-monitoring of behavior, shaping knowledge, and medication reminders | ARMS | Mean ± SD at 90 days 18.12 ± 3.84 Mean ± SD at 180 days 17.56 ± 3.51 (P = 0.295) (ns) | - |
| **Huang *et al.* [20]** | Usual care | Medication scheduling, reminder, tracking, data sharing, and medication adherence assessments | ASK-12 | ASK-12 Mean ± SD IG = 28.6 ± 5.2, CG = 25.5 ± 4.4 (P = 0.01) | Mean ± SD in HbA1c IG = 9.0 (1.6), CG = 9.4 ± 2.4 (P = 0.57) (ns) |
| **Chao *et al.* [21]** | Usual care | Integrates and displays patients' information, education that integrates with patient-collected information, and behavioral changes assessment | Mobile questionnaire | Mean ± SD pre-intervention = 4.6 ± 0.7, post-intervention = 4.4 ± 1.0 (P = 0.42) (ns) | Change in HbA1c (P = 0.003) |
| **Yang *et al.* [17]** | Usual care | Data collection, transmission of data to the server, and reminders | MMAS-6 | Mean change IG = 0.52, CG = 0.45 (P = 0.01) | Mean change in HbA1c IG = −0.63, CG = −0.28 (P = 0.003) |
| **Batch *et al.* [16]** | Usual care | Patient education through an interactive learning experience | Voils score | Mean change IG = −0.18 (p = 0.11) ns | Mean change in HbA1c IG = −0.32, CG = −0.39 (P = 0.78) (ns) |
| **Orozco-Beltrán *et al.* [22]** | Usual care | Data from the commercially available devices were wirelessly received by the app for consultation | MARS-5 | Mean adherence IG = 24.3, CG = 23.0 (P = 0.05) | Mean reduction in HbA1c IG = −0.81 (0.89), CG = −0.15 (1.03) (P = 0.03) |

ARMS = adherence to refills and medication scale; ASK-12 = adherence starts with knowledge-12; CG = control group; HbA1c = haemoglobin A1c; IG = intervention group; MARS-5 = medication adherence report scale; MMAS-6 = 6-item Morisky medication adherence; ns = not significant; SD = standard deviation.

## *Features of the Applications*

The mobile applications utilized diverse methods to support disease control and promote medication compliance. These methods included alerts for medications, delivery of instructional materials, data monitoring, and interactions with medical experts. Four of the apps sent notification-based reminders for medications, helping users recall and follow their dosing regimens. Three apps featured educational modules or training components to deepen users' knowledge of T2DM, its therapies, and lifestyle guidance.

One app included prompts for blood glucose checks to gather data for tracking physiological reactions, with notifications triggered if entered values fell outside set thresholds. Five apps enabled bidirectional exchanges between participants

and clinical personnel, encouraging involvement and assistance.

### Adherence Measures

Every study reviewed relied on subjective methods for measuring adherence, as outlined in **Table 4**. The table highlights both significant and non-significant results, marking the latter as 'ns'. Nonetheless, discrepancies emerge due to differences among the publications. Self-report surveys were applied in all seven studies to assess adherence: the Voils score (n=1), adherence starts with knowledge-12 (n = 1), Medication adherence report scale (n = 1), adherence to refills and medication scale (n=1), and 6-item Morisky medication adherence scale (n = 1) served as the instruments in five cases, whereas the other two did not identify the specific tool. Interestingly, just one study used a mobile platform to administer the survey. Overall, four of the seven studies showed statistically significant gains in medication adherence for T2DM patients, linked to the mobile app intervention.

### Effects in Improving Health Outcomes

Although the studies did not evaluate patient health results directly in relation to medication adherence, they examined alterations in physiological markers as a proxy. For thorough insights, the ensuing observations emphasize studies that recorded variations in clinical metrics, particularly the statistical relevance of those variations. Six of the seven studies incorporated assessments of clinical health indicators, specifically HbA1c concentrations. Of these, four demonstrated statistically significant reductions in blood glucose, whether across intervention and control arms or in follow-up evaluations. One study omitted health outcome data. Another indicated a health outcome shift that lacked statistical significance.

### Quality Assessment

The appraisal of potential bias in the selected studies is displayed in **Tables 5 and 6**. Out of the seven studies, five received a high-quality rating, one was deemed of moderate quality, and one was rated as low quality.

**Table 5.** Summary of risk of bias for randomised controlled trials

| Study | D1 | D2 | D3 | D4 | D5 | Overall |
|---|---|---|---|---|---|---|
| **Chao *et al*. [21]** | Low | Unclear | Low | Unclear | Low | Unclear |
| **Huang *et al*. [20]** | Unclear | Low | Low | Low | Low | Low |
| **Kleinman *et al*. [18]** | Low | Unclear | Low | Low | Low | Low |
| **Orozco-Beltrán *et al*. [22]** | Low | Low | High | Unclear | High | High |
| **Yang *et al*. [17]** | Unclear | Low | Low | Low | Low | Low |

D1 = bias due to randomisation process; D2 = bias due to incomparable groups at baseline; D3 = bias due to incomplete outcome data; D4 = bias due to lack of binding of outcome assessors; D5 = bias due to non-adherence of participants to the assigned intervention.

**Table 6.** Summary of risk of bias for non-randomised studies

| Study | D1 | D2 | D3 | D4 | D5 | Overall |
|---|---|---|---|---|---|---|
| **Batch *et al*. [16]** | Low | Low | Unclear | Unclear | Low | Low |
| **Kjos *et al*. [19]** | Low | Low | Low | High | Low | Low |

D1 = bias due to lack of representativeness in the population; D2 = bias due to inappropriate outcome and intervention measurements; D3 = bias due to incomplete outcome data; D4 = bias due to confounding factors; D5 = bias due to deviation from intended intervention.

A major issue related to bias stemmed from insufficient descriptions of the randomization procedures. This shortfall in documentation casts uncertainty over the integrity of group assignments, which could affect how participants were allocated to intervention versus control arms. An additional bias risk involved ambiguity in establishing baseline equivalence between groups. This ambiguity creates questions about pre-existing disparities between the experimental and comparison cohorts, thereby undermining the precision of evaluations concerning the intervention's effects and the robustness of the results.

Furthermore, two investigations featured ambiguous blinding for outcome evaluators. Such vagueness in blinding protocols can introduce bias through subjective influences on the interpretation of results. Another biased source involved missing outcome data, especially evident in one study where a substantial dropout rate signaled a high bias risk. Attrition due to incomplete data can distort estimates of the intervention's actual effects, thereby reducing the trustworthiness of the conclusions.

This systematic review examined published research to determine the efficacy of mobile device apps in boosting medication compliance for individuals with type 2 diabetes mellitus (T2DM). While all seven studies indicated favorable results from app-based interventions relative to controls in terms of adherence, three failed to achieve statistical significance in adherence improvements. In parallel, just four studies revealed statistically meaningful reductions in HbA1c concentrations [23-25].

Collectively, the apps' functionalities foster a superior user journey and better clinical results. Medication prompts help maintain steady compliance by minimizing forgotten doses and encouraging regimen adherence. Sharing educational materials equips users with valuable insights into their disorder, therapies, and essential behavioral changes, fostering self-reliance and informed choices. Monitoring tools allow active oversight of physiological indicators, supporting customized, evidence-based strategies for condition control. Moreover, built-in interactive links to clinicians create an enabling framework for immediate exchanges, swift doubt resolution, and customized adjustments aligned with personal requirements [26-28].

This comprehensive blending of elements embodies a user-focused paradigm, in which digital tools extend beyond mere dosing support to actively involve and enable people, spurring greater initiative and awareness in their wellness oversight. With evolving tech capabilities, continued enhancements, and broader scopes for these elements, signal potential for amplified benefits from mobile apps in patient outcomes and broader care effectiveness [27-29].

Self-report surveys stand as a common subjective technique for evaluating compliance. These surveys offer the most direct and uncomplicated way to collect details, providing a cost-effective and practical means for adherence evaluation in real-world research and routine care. They typically involve participants describing their own medication-taking patterns. Key advantages include low expense, unobtrusiveness, limited burden on respondents, ease of use, and flexibility in administration timing and format [25-27].

However, limitations of self-report surveys warrant attention, such as the risk of participants supplying untruthful responses. This might arise from influences like social desirability bias, prompting individuals to portray themselves positively. As a result, investigators must be cautious of self-report constraints and explore supplementary verification strategies when feasible. Additionally, surveys may pose challenges for those with reduced literacy [26-28].

The present review highlighted considerable diversity in the self-report tools for adherence used in the studies. Although this diversity complicates straightforward comparisons, it also underscores the versatility of app interventions in varied investigative settings and groups. Applying different validated instruments illustrates that adherence gains were evident under several evaluative lenses. Even with variances in survey formats, scoring approaches, and reliability traits potentially influencing results, the prevailing pattern across the research affirms the beneficial role of mobile apps. No universal top choice exists for the optimal adherence survey, as selection hinges on elements like the target demographic, study or practice environment, and assessment goals.

### *Strengths and Limitations*

This review, which examines the use of mobile applications by patients with type 2 diabetes mellitus (T2DM) and their effects on compliance, adopts a comprehensive methodology by including studies regardless of their research design or the caliber of the apps involved. Although this broad inclusion yields a well-rounded view, it also brings both advantages and drawbacks. It delivers an expansive summary of the field, yet it creates issues stemming from variability. The integration of both randomized controlled trials (RCTs) and non-RCT designs holds importance. Although quality thresholds did not dictate exclusions, every chosen study was rated as having a moderate to high quality. This suggests that the review drew on the most reliable data available on the topic. However, the methodological and clinical differences across studies posed a key constraint, complicating the formulation of consistent conclusions. Moreover, limiting the scope to English-only publications could foster language bias, possibly overlooking key contributions from non-English sources.

In addition, excluding patients with type 1 diabetes, prediabetes, or gestational diabetes defines a narrow focus, reducing the applicability of results to the wider diabetic community. Depending on self-reports to measure adherence opens the door to response bias, casting doubt on the precision and dependability of the compliance information. The differences in app functionalities and their intricacies also heighten the variability, which may affect the general performance of the examined applications.

It is essential to acknowledge uncontrolled factors that this review did not analyze in depth, such as age, sex, cultural influences, education, and economic conditions. These elements can substantially shape patient compliance and merit attention in subsequent studies to provide deeper insights into how app usage, adherence, and patient profiles interconnect.

## Conclusion

This systematic review explored the role of mobile applications in fostering medication compliance among T2DM patients. Each of the seven studies observed positive effects from app interventions relative to controls in boosting adherence. That said, only four achieved statistical significance in this regard. Similarly, merely four studies demonstrated statistically meaningful reductions in HbA1c levels. Nevertheless, firm judgments about the apps' efficacy and their influence on adherence and clinical results proved difficult, owing to the generally modest quality of the evidence and substantial inconsistencies in research approaches, app attributes, and evaluation metrics. The bulk of the data originated from preliminary trials exhibiting mostly low bias risks. Additional progress is needed, and upcoming research ought to prioritize developing uniform guidelines for assessing app-driven interventions aimed at adherence. Such efforts would seek to identify the most effective app elements while improving accessibility and incorporating user-oriented designs to encourage long-term compliance and better health results.

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