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Original Research

Improving Glycemic Control in Adults and Children With Type 1 Diabetes With the Use of Smartphone-Based Mobile Applications: A Systematic Review

Cathy Sun MD ^a; Janine C. Malcolm MD, FRCPC ^a; Bertha Wong MD, FRCPC ^b; Risa Shorr MLIS ^c; Mary-Anne Doyle MD, MSc, FRCPC ^{a,d,*}

^a Division of Endocrinology and Metabolism, University of Ottawa, Ottawa, Ontario, Canada

^b Division of Endocrinology and Metabolism, William Osler Health Systems, Toronto, Ontario, Canada

^c The Ottawa Hospital, Ottawa, Ontario, Canada

^d The Ottawa Hospital Research Institute, Ottawa, Ontario, Canada



Key Messages

- Smartphone mobile applications may provide additional support for improving glycemic control and clinical outcomes in patients with type 1 diabetes.
- Despite a vast array of relatively inexpensive and accessible mobile apps, there is a paucity of well-designed studies evaluating the role of these tools in the management of type 1 diabetes.
- There is a need for larger, longer and good-quality studies to explore the efficacy of mobile applications in optimizing outcomes in type 1 diabetes.

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ABSTRACT

Objectives: Management of type 1 diabetes is often challenging. Smartphone mobile applications (apps) may provide additional support and help to improve glycemic control and clinical outcomes. The objectives of this study were to examine the literature evaluating the use of mobile apps (stand-alone and text messaging/feedback) in type 1 diabetes and to review top-rated mobile apps applicable to type 1 diabetes. **Methods:** Medline, Cochrane and Embase databases were systematically searched to identify studies published from inception to February 2018. Top-rated relevant apps from Google Play Store and Apple App Store were reviewed in July 2017.

Results: The literature search yielded 3,462 studies. Of these studies, 9 evaluated the stand-alone apps; 3 showed significant improvement in glycated hemoglobin (A1C) levels (0.5%, $p < 0.05$, 0.57%, $p < 0.05$, and 0.58%, $p = 0.02$); 3 demonstrated improved adherence to glucose monitoring; and 1 study demonstrated a reduction in hypoglycemic events (glucose < 3.0 mmol/L) in 6 of 10 participants who completed the study. Also, 5 studies evaluated a mobile app plus text-messaging/feedback system. Only 1 showed a significant reduction in severe hypoglycemic events (mobile app+text, IQR 0.33, 95% CI 0.17 to 0.63; vs. control, IQR 2.29, 95% CI 1.80 to 2.91), while another single study demonstrated a reduction in median glycated hemoglobin levels (0.3%; $p < 0.001$). Most top-rated mobile apps logged parameters relevant to diabetes management, and some provided graphic analysis and set reminders.

Conclusions: This study highlights the need for larger and longer studies to explore the efficacy of apps to optimize outcomes in type 1 diabetes, the populations that would benefit most from these tools and the resources needed to support mobile apps plus text-messaging/feedback systems.

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* Address for correspondence: Mary-Anne Doyle, MD, MSc, FRCPC, 1967 Riverside Drive, 4th floor, Division of Endocrinology and Metabolism, The Ottawa Hospital, Ottawa, Ontario, Canada.

E-mail address: madoyle@toh.ca

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R É S U M É

Mots clés :
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 applications mobiles
 prise en charge autonome
 messagerie texte
 diabète de type 1

Objectifs : La prise en charge du diabète de type 1 est souvent difficile. Les applications mobiles intelligentes (applis) peuvent fournir un support supplémentaire et aider à améliorer le contrôle de la glycémie et les résultats cliniques. Les objectifs de cette étude étaient d'explorer la littérature évaluant l'utilisation d'applications mobiles (autonomes et avec messagerie texte/avec commentaires) dans le diabète de type 1 et d'examiner les applications mobiles consacrées au diabète de type 1 les mieux notées.

Méthodes : Les bases de données Medline, Cochrane et Embase ont été systématiquement considérées pour identifier les études publiées originellement jusqu'à février 2018. Les applications pertinentes les mieux notées sur le Play Store de Google et l'App Store d'Apple ont été évaluées en juillet 2017.

Résultats : La recherche documentaire a atteint 3 462 études. Parmi ces études, 9 ont évalué les applications autonomes; 3 ont montré une amélioration significative des taux d'hémoglobine glyquée (0.5%, $p < 0.05$, 0.57%, $p < 0.05$, et 0.58%, $p = 0.02$); 3 ont démontré une meilleure adhésion à la surveillance de la glycémie; et 1 étude a démontré une réduction des événements hypoglycémiques (glucose < 3.0 mmol/L) pour 6 des 10 participants ayant terminé l'étude. En outre, 5 études ont évalué une application mobile ainsi qu'un système de messagerie texte/avec commentaires. Une seule a montré une réduction significative des événements hypoglycémiques graves (application mobile+texte, EI 0.33, IC à 95% 0.17 à 0.63, vs. contrôle EI 2.29, IC à 95% 1.80 à 2.91), tandis qu'une autre étude isolée a démontré une réduction des niveaux médians d'hémoglobine glyquée (0.3%, $p < 0.001$). La plupart des applications mobiles les mieux notées ont consigné des paramètres pertinents pour la gestion du diabète, et certains ont fourni des analyses graphiques et mis en place des rappels.

Conclusions : Cette étude souligne le besoin d'études plus vastes et plus longues pour explorer l'efficacité des applis pour optimiser les issues dans le diabète de type 1, les populations qui bénéficieraient le plus de ces outils et les ressources nécessaires pour soutenir les applications mobiles ainsi que les systèmes de messagerie texte/avec commentaires.

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Introduction

The management of type 1 diabetes is often complex, challenging and time consuming. Despite the well-established benefits and improved outcomes associated with optimal glycemic control, attaining glycemic targets remains a challenge and a burden for many patients (1–3). The rise of smartphone mobile applications (apps) over the past decade has led to increasing interest in using this technology to assist in chronic-disease management. Effective tools to support patients in their self-management may enhance quality of life and help to reduce complications.

Mobile health is a new term recently recognized by the World Health Organization; it refers to the use of mobile applications and texting to help in the management of medical conditions (4). Many mobile apps have the added feature of telemonitoring, which allows for the direct transmission of patients' data to their health-care teams and that, in turn, facilitates more frequent feedback and support (4). The appeal of mobile apps includes their portability, data logging and transmission capabilities and the ability to facilitate personalized feedback via the app or a health-care provider.

There have been studies of mobile apps and their effectiveness in diabetes management (5–7). However, most of these studies have been limited to patients with type 2 diabetes or have included a combination of patients with both type 1 diabetes and type 2 diabetes (8–10). Although Hou et al demonstrated that the use of mobile apps was associated with an improvement in glycated hemoglobin (A1C) levels in patients with type 2 diabetes (0.49%, 95% CI 0.30 to 0.68), the same response has not been demonstrated in patients with type 1 diabetes.

This study and analysis were limited to randomized controlled trials (RCTs), omitted many nonrandomized studies and did not differentiate between stand-alone mobile apps and mobile apps that included text messaging. Patients with type 1 diabetes have greater fluctuations in blood glucose levels and require frequent blood-glucose monitoring and insulin-dose adjustments based on diet and physical activity, so mobile apps may play an important role in providing support for type 1 diabetes self-management. Assessing the current evidence for type 1 diabetes self-management with mobile

apps will help to guide our recommendations to patients regarding their usage and their potential benefits and limitations.

Objectives

The primary objective of this study was to summarize the evidence supporting the use of stand-alone mobile apps in the management of type 1 diabetes. We further evaluated the benefits of mobile apps that include text messaging features and/or allowed communication with the health-care teams. As a secondary objective, we evaluated mobile apps available for the management of type 1 diabetes through the Google Play Store and Apple App Store.

Methods

Search strategy

A comprehensive systematic literature search was completed by an information specialist trained in the conduct of systematic reviews. We used Medical Subject Heading terms and free-text terms for the included population, interventions and outcomes specified that were as inclusive as possible (Supplementary Material). We identified all potentially relevant studies through a formal comprehensive and systematic literature search of MEDLINE, Embase and Cochrane databases for studies published from inception through February 2018 using Medical Subject Heading and free text terms to locate all possible studies.

Study inclusion and exclusion criteria

Inclusion and exclusion criteria were defined a priori in a protocol designed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (11). Studies were included if they were conducted in participants with type 1 diabetes, contained at least 1 study group that evaluated a stand-alone mobile app or a mobile app plus a text-messaging/feedback system and included a comparison group. All included studies were also required to include evaluation of the intervention(s) on at least

1 of the following: A1C levels, adherence to glucose monitoring, adherence to insulin regimens, hypoglycemia episodes or emergency department visits for hypoglycemia or hyperglycemia emergencies. We included RCTs, non-RCTs, cohort studies, case-control studies and studies that clearly reported mean differences, p values, relative risks or odds ratios or provided data for their calculation. Only studies published in English were included.

Studies were excluded if they were not limited to type 1 diabetes or if the mobile app was part of an insulin pump or closed-loop system related to an insulin pump and/or continuous glucose monitoring. Case reports, case series, conference proceedings, letters, commentaries, editorials and short studies that were not full-length articles were also excluded. For publications using the same patient population, only the most comprehensive study was used.

Study screening and selection process

Following the comprehensive literature search, the titles and abstracts of selected studies were screened by 2 independent assessors (CS, MD) to identify studies for full-text retrieval. If no abstract was available, then the full text was obtained unless the study could be clearly eliminated based on titles alone. All abstracts remaining after the first screening phase were kept for the second phase during which full texts were screened by 2 of the 3 independent assessors (CS, BW, MD) and included in the systematic review based on eligibility criteria. The same inclusion and exclusion criteria were used at each screening stage. Disagreements between reviewers were resolved by discussion and involved a third reviewer if necessary.

Data extraction

Data from the selected studies were extracted by 2 of the 3 reviewers (CS, BW, MD) using a standardized data-extraction form and were summarized in a structured table. The following data were extracted from each study: author, year of publication, study design and study population. Data concerning demographics, duration of diabetes, length of follow up and outcome-related information were also extracted. Disagreements between reviewers were resolved by discussion or by a third reviewer.

Statistical analysis

The outcomes to be evaluated were determined a priori and included changes in A1C levels, adherence to glucose monitoring, adherence to insulin regimens, reduction in hypoglycemia events and emergency department visits for hypoglycemia or hyperglycemia emergencies. A descriptive analysis of all included studies was performed. The unadjusted and adjusted risk estimates were retrieved and compared for all included studies. Differences between study populations, design, characteristics, interventions and outcomes were evaluated. The outcomes were not combined statistically due to clinical and methodologic heterogeneity.

Risk of bias assessment

The quality of studies was analyzed by 2 reviewers. Risk of bias was assessed using the Cochrane risk-of-bias tool (12) and the Cochrane risk-of-bias tool for nonrandomized studies (13). Subgroup analyses based on risk of bias were defined a priori.

Mobile applications relevant to the self-management of type 1 diabetes

To obtain a representative selection of the variety of apps available to patients, we searched for mobile apps applicable to patients' self-management of type 1 diabetes in the Google Play Store and

Apple App Store. The keywords used for the search were based on consensus from the authors: "glucose monitoring," "carbohydrate counter" and "exercise and diabetes." The Google Play Store allowed sorting the search results by user rating, with the best rating category being 4+ stars. No method was available to further rank the apps in this category, so the first 5 apps in each keyword search result category were chosen to be analyzed. The Apple App Store allowed sorting by iPhone only and by medical category and were ranked according to users' ratings. Therefore, the top 5 apps in each keyword search category were chosen. We summarized the key features and costs associated with each mobile app.

Results

A comprehensive search of MEDLINE, Embase and Cochrane Collection through February 2018 yielded 3,462 results. We identified 117 studies during the initial screening process, and the full texts were retrieved for further analysis. As outlined in Figure 1, 14 studies (14–27) met the inclusion and exclusion criteria following the full-text review. Of the studies, 9 (14–22) focused on stand-alone mobile apps and 5 studies (23–27) evaluated the benefits of mobile apps plus text messaging (Figure 1). The main characteristics of the 14 studies identified in this systematic review are summarized in Table 1.

Stand-alone mobile apps

Nine studies (14–22) evaluated the benefits of stand-alone mobile apps in the management of type 1 diabetes (4 nonrandomized pre-post pilot studies and 2 RCTs). These studies consisted of 553 participants with type 1 diabetes, and each study sample size ranged from 20 to 180 participants. These studies were short in duration (follow up 3 to 6 months) (Table 1).

Impact on A1C levels

Of the studies, 4 assessed a change in A1C levels as the main outcome of interest (14–17). Charpentier et al randomized participants (N=180) to the Diabeo app or standard care for 6 months (14). The Diabeo app featured an insulin bolus calculator and established plasma glucose targets and algorithms to adjust insulin dosages if blood glucose readings were off target. The use of the mobile app was associated with a significant decrease in A1C levels of 0.5% (SD 0.9; $p < 0.05$). In a pre-post study (N=30), the Diastat app was used, and it provided blood glucose trends and recommended insulin doses based on similar situations in the participants' pasts (15). After 3 months, there was a significant decrease in A1C levels compared to baseline: preintervention 8.20% (SD 1.1) vs. postintervention 7.63% (SD 0.3; $p < 0.05$). Although a relatively large RCT (N=92) by Goyal et al did not show overall improvements in A1C levels, a subgroup analysis of participants using the bant mobile app and testing more than 5 times per day was associated with a 0.58% ($p = 0.02$) lowering of A1C levels (16). Another 5 studies showed no significant improvement in glycemic control (17–21) (Table 1).

Impact on adherence to glucose monitoring

Three studies found that stand-alone mobile apps improved adherence to glucose monitoring (14,17,21). The most significant improvements (1.5- to 2.0-fold increases) were noted in the studies using the bant mobile app, which was designed to promote blood glucose monitoring and trend analysis in patients with type 1 diabetes (16,21).

Risk of bias

Of the 3 RCT studies, 2 were found to have low to moderate risk of bias (16,19), and 1 had a high risk of bias (14). All nonrandomized

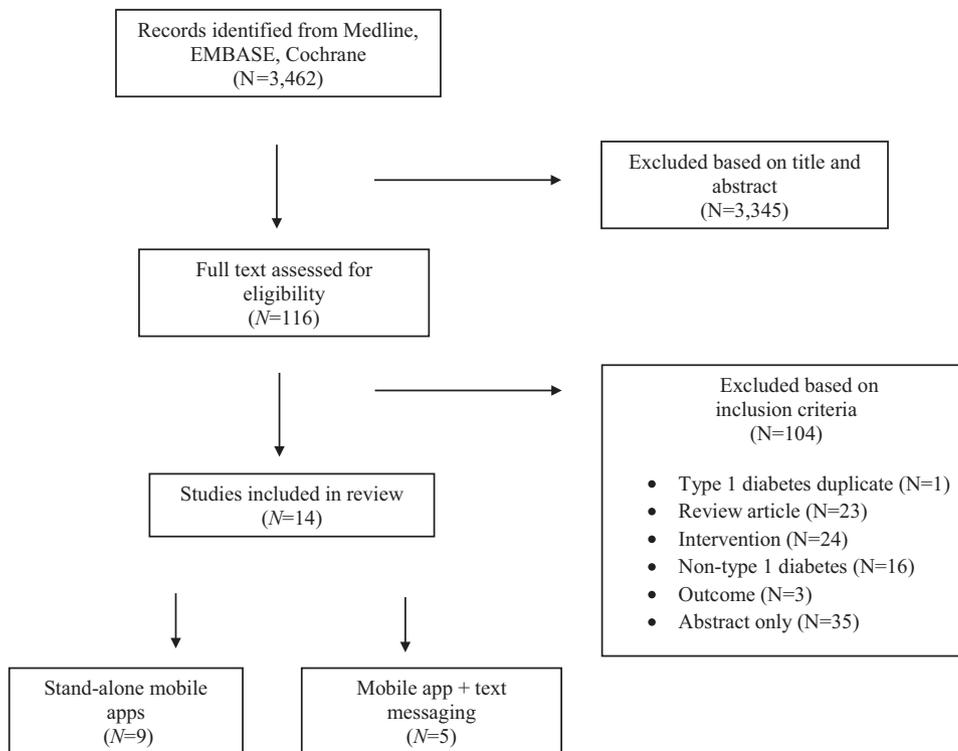


Figure 1. Selection process to identify relevant studies. *App*, mobile application.

studies were considered to have moderate to high risk of bias and suffered from confounding bias (Table 2, A and 2, B).

Mobile app plus text-messaging system

Of the studies (Table 1), 5 investigated the role of mobile apps plus a text-messaging system (23–27). These studies were small (a total of 270 participants) and had sample sizes that ranged from 12 to 127 participants. The follow-up duration ranged from 3 to 9 months. The mobile apps used in these 5 studies encouraged participants to log their blood glucose measurements, incorporated carbohydrate-counting features, considered the participants' physical activities and allowed for text messaging or feedback with a member of the health-care teams.

Impact on A1C levels

No statistically significant improvements were noted in A1C levels. However, 2 studies demonstrated a trend toward improved A1C levels (−0.33% to −1.28%) (23,26).

Two studies assessed the use of the Diabetes Interactive Diary app. This mobile app features the dual function of data transmission to health-care teams and communication between patients and their health-care teams via text messaging. The first study (23) showed that fasting blood glucose levels decreased by 6.7% (95% CI 11.9 to −1.6; $p=0.01$), and postprandial glucose levels decreased by 11.5% (95% CI −19.3 to −3.7; $p=0.01$). The second study by this group did, however, demonstrate a significant reduction in the incidence of severe hypoglycemic events (IQR 0.33; 95% CI 0.17 to 0.63 [app+text] vs. IQR 2.29; 95% CI 1.80 to 2.91 [control]) (25). The second study had a larger number of participants, and the duration of the study was 6 months.

Froisland et al used the Diamob app, which is based on the patients' taking pictures of meals and then inputting the carbohydrate contents and insulin boluses (24). The picture, along with the

carbohydrate contents and insulin boluses that the patients entered, can be accessed by the health-care team, and it allowed for educational messages to be sent to participants. Although there was no significant difference in the A1C levels and diabetes knowledge test before and after using Diamob, patients preferred the text-messaging component and felt that they had increased access to their health-care teams and an increased sense of security that their health-care teams were reviewing the data.

Ryan et al studied the use of the Intelligent Diabetes Management app, in which participants recorded their glucose readings, their anticipated carbohydrate intakes and their planned physical activities (27). The app used the participants' individualized insulin dosing parameters to suggest an insulin dose for the proposed food intake. Health-care providers monitored the participants' blood glucose records and sent feedback to the participants at weeks 2, 4, 8, 12 and 16 of the 4-month study period. There was a significant decrease in median A1C levels at the end of the study (preintervention median A1C 8.1% [IQR 7.5 to 9.0]; postintervention median A1C 7.8% [IQR 6.9 to 8.3]; $p<0.001$).

Risk of bias

Risk of bias was assessed as moderate to high in all but 1 study (25) (Table 2, A and 2, B).

Diabetes management-related mobile apps from Google Play and Apple apps

Our review of a sample selection of mobile apps available through the Google Play Store and Apple App Store revealed a vast number of mobile apps available to support the management of type 1 diabetes. We identified and reviewed 30 top-rated apps for glucose monitoring, carbohydrate counting or exercise as of July 2017. The costs of the mobile apps identified ranged from no cost to \$27.99. The key features of each app are summarized in Table 3.

Table 1

A. Characteristics of stand-alone mobile app studies. B. Characteristics of mobile app plus texting/feedback from health-care professionals studies

A							
Author (year)	Country	Study design	Study duration (months)	Participants	Mobile app	Comparator	Outcome
Franc (2009)	France	Pre/post	4	35	e-diary	Pre/post	Decrease A1C (nonsignificant): pre 7.8% SD 0.9; post 7.3% SD 0.6
Charpentier (2011)	France	RCT	6	180	Diabeo	Usual care	Daily CBG checks increased: 3.29 to 3.57 (p<0.05); A1C decreased by 0.5% SD 0.9; p<0.05
Cafazzo (2012)	Canada	Pre/post	3	20	Bant	Pre/post	Daily CBG checks increased: 2.4 to 3.6 (p<0.05)
Skrovseth (2012)	Norway	Pre/post	3	30	FTA	Pre/post	No significant change in A1C pre 8.3% SD 1.4; post 8.3% SD 1.3
Drion (2015)	Netherlands	RCT	3	63	DBEES	Usual care	No significant change in A1C: Intervention: pre 7.7% SD 0.3; post 7.9% SD 0.4
Skrovseth (2015)	Norway	Pre/post	3	30	Diastat	Pre/post	Decrease in A1c: pre 8.20% SD 1.11; post 7.63% SD 0.3 (p<0.05)
Goyal (2017)	Canada	RCT	3	92	Bant app	Usual care	No change in A1C But subgroup of users with >5 SMBG daily had statistical improvement in A1C by 0.58% (p=0.02)
Clements (2017)	USA	Retrospective cohort	3.6 (mean)	81	Glucometer connected mobile app	Usual care	No change in A1C or mean blood glucose 2.3×increase SMBG frequency (p<0.01)
Feurstein-Simon (2018)	USA	Pre/post	3	22	Glooko	Pre/post	10/22 participants completed the study 6 completers had fewer daytime episodes of glucose <54 mg/dL 50% of completers had a reduction in daytime hypoglycemia
B							
Author (Year)	Country	Study design	Study duration (months)	Participants	Mobile app+HCP	Comparator	Outcome
Rossi (2009)	Italy	Pre/post	9 (median)	41	Diabetes Interactive diary	Pre/post	Decrease A1C (nonsignificant): pre 7.6% SD 0.3; post 7.27% SD 0.4
Froisland (2012)	Norway	Pre/post	3	12	Diamob	Pre/post	No significant change in A1C: pre 8.3% SD 0.3; post 8.1% SD 0.9
Kirwan (2013)	Australia	RCT	6	72	Glucose Buddy	Usual care	Decrease in A1C (nonsignificant): Intervention pre 9.1% SD 1.2, post 7.8% SD 0.8. Control pre 8.5% SD 0.9, post 8.6% SD 1.2
Rossi (2013)	Italy	RCT	6	127	Diabetes Interactive Diary	Usual care	Reduction in incidence of severe hypoglycemia: IR 0.33; 95% CI 0.17–0.63 (app+text) vs. IR 2.29; 95% CI 1.80–2.91 (control)
Ryan (2017)	Canada	Pre/post	5	18	Intelligent Diabetes Management	Pre/post	Decrease in median A1C: pre 8.1% (IQR 7.5–9.0); post 7.8% (IQR 6.9–8.3); p<0.001

A1C, glycated hemoglobin; ABC4D, Advances Bolus Calculator for Diabetes; CBG, capillary blood glucose; CI, confidence interval; DBEES, Diabetes Under Control; e-diary, electronic diary; FTA, Few Touch Application; HCP, health-care provider; IQR, interquartile range; IR, incidence rate per participant per year; RCT, randomized controlled trial; SD, standard deviation; SMBG, self-monitored blood glucose.

Table 2

A. Cochrane Collaboration's tool for assessing risk of bias for randomized controlled trials (11). B. Cochrane Collaboration's tool for assessing risk of bias for nonrandomized controlled trials (12)

A							
Studies	Adequate sequence generation	Allocation concealment	Blinding	Incomplete outcome data addressed	Free of selective reporting	Free of other bias	
Charpentier (2011)	Unclear	Unclear	No	Yes	Yes	Yes	
Kirwan (2013)	Unclear	Unclear	No	Yes	Yes	Yes	
Rossi (2013)	Yes	Yes	No	Yes	Yes	Yes	
Drion (2015)	Yes	Yes	No	Yes	Yes	Yes	
Goyal (2017)	Yes	No	No	Yes	Yes	Yes	
B							
Studies	Bias in confounding	Bias in selection	Bias in classification of intervention	Bias in deviations in intended intervention	Bias in missing data	Bias in measurement of outcome	Bias in reported result
Franc (2009)	High	Moderate	Low	Low	Unclear	Moderate	Unclear
Cafazzo (2012)	High	Moderate	Low	Low	Unclear	Moderate	Unclear
Skrovseth (2012)	High	Moderate	Low	Low	Low	Moderate	Low
Rossi (2009)	High	Moderate	Low	Low	Moderate	Moderate	Unclear
Froisland (2012)	High	Moderate	Low	Low	Low	Moderate	Unclear
Ryan (2017)	High	Moderate	Low	Low	High	Moderate	Unclear
Clements (2017)	Moderate	Low	Low	Low	Moderate	Low	Unclear
Feurstein-Simon (2018)	High	Moderate	Low	Low	High	Moderate	Unclear

Table 3

Features of glucose monitoring mobile apps, carbohydrate counter mobile apps and diabetes and exercise mobile apps

Glucose monitoring mobile apps	Free	Logs	Scope covers glucose, food and exercise	Data Summary	Reminders	Patient education
Google Play Store						
Blood glucose tracker	✓	✓		✓	✓	✓
Glucose Buddy	✓	✓	✓	✓	✓	
Calorie Counter	✓	✓	✓	✓		✓
Samsung Health	✓	✓	✓			✓
Medisafe	✓	✓			✓	
Apple App Store						
Diabetes Assistant		✓		✓	✓	
BP Assistant & Diabetes Assistant		✓		✓	✓	
BGluMon		✓		✓		
Glooko	✓	✓	✓	✓	✓	✓
Dexcom G5	✓	✓		✓	✓	
Carbohydrate counter mobile apps	Free	Logs	Scope covers glucose, food, exercise	Data summary	Reminders	Patient education
Google Play Store						
Calorie, Carb & Fat Counter	✓	✓				
MyKeto-Low Carb Counter	✓	✓		✓		
Serenity Simple Carb Counter		✓		✓		
MyFitnessPal Calorie Counter	✓	✓		✓		
Calorie Counter- MyNetDiary	✓	✓	✓	✓		✓
Apple App Store						
Calories Minute		✓	✓	✓		
Glucose Buddy	✓	✓	✓	✓	✓	
Carbs Control		✓		✓		
Carb Master		✓	✓	✓		
A Low GI Diet						
Exercise and diabetes mobile apps	Free	Logs	Scope covers glucose, food, & exercise	Data summary	Reminders	Patient education
Google Play Store						
Exercise Diabetes	✓	✓				✓
Samsung Health	✓	✓	✓			✓
Glucose Zone	✓	✓				
Diabetic Diet	✓		✓			✓
20Min Beginners Workout	✓					
Apple App Store						
GenieMD	✓	✓	✓	✓		✓
My Diet Diary	✓	✓	✓	✓		✓
Get Fit with Andrew Johnson					✓	
Relax with Andrew Johnson					✓	
Diabetes Diary		✓		✓		✓

Most of the apps had logging functions and the ability to summarize data. Only 12 of 30 apps covered the full scope of diabetes self-management (glycemic control, carbohydrate intake and exercise). In 11 of 30 apps, patients were able to set reminders for testing blood glucose, and 11 apps also provided patients with education or motivation concerning at least 1 aspect of diabetes self-management, such as patterns of carbohydrate intake, suggested insulin bolus dosages when blood glucose was out of the desired range, insulin bolus calculators or positive feedback based on logged data.

Discussion

This study suggests that both stand-alone mobile apps and mobile apps plus text messaging systems have the potential to improve diabetes self-management skills in patients with type 1 diabetes. Stand-alone mobile apps increased the frequency of daily blood glucose checks (14,21) and significantly decreased A1C levels (14,15) during a relatively short follow-up period. In contrast, although improvements in A1C levels were not as robust in studies evaluating mobile apps with text-messaging components, these studies showed improvement in fasting and postprandial glucose levels (23), decreased incidence of severe hypoglycemia (25) and decreased median A1C levels (27). The added benefit of these apps was increased feedback for patients from their health-care provider teams between appointments. However, in the studies that used text messages for providing feedback (23,25), there was high variability in the number of text messages exchanged during the study period, which may reflect differing degrees of patient engagement and responsiveness to feedback.

No studies compared stand-alone mobile apps with mobile apps with text-messaging systems. Comparing these different types of mobile apps would help to determine whether the extra resources associated with the text messaging component improve outcomes.

Similar to our findings of glycemic improvement in type 1 diabetes, 2 recent meta-analyses demonstrated a reduction in A1C levels of 0.4% to 0.49% with the use of mobile apps in patients with type 2 diabetes (9,10). The meta-analysis by Hou et al reviewed 14 RCTs that had a total of 1,360 participants. They demonstrated a mean reduction in A1C levels of 0.49% (95% CI 0.30 to 0.68; $I^2=10\%$) in participants who used the apps (10). The systematic review by Cui et al included 13 RCTs and a meta-analysis of 6 RCTs that included 1,022 patients (9). They found a mean reduction in A1C levels of 0.40% (95% CI 0.11 to 0.69; $p=0.007$). The follow-up duration ranged from 3 months to 1 year (9). Both studies recommended that future studies have longer follow-up periods to see whether the effects are sustainable (9,10). These results are comparable to studies evaluating stand-alone mobile apps in patients with type 1 diabetes and suggest that the A1C lowering is not specific to type 1 diabetes.

Limitations

The results from this study are encouraging, but there are limitations that should be considered. A major limitation was the study design and small sample size of the included studies. Of the 14 studies, only 5 were RCTs (14,16,19,25,26), and only 1 had a low risk of bias (19). None of these were blinded, and 2 (14,26) had unclear information about sequence generation and allocation concealment. There was moderate to high risk of bias in other studies (Table 2, A and 2, B).

The length of follow up ranged from 3 months (8 of 14 studies) to 9 months (1 study). Changes in A1C levels were evaluated in most studies. However, it takes approximately 3 months for A1C levels

to change, so these shorter studies may not have been long enough to demonstrate significant effects.

Another important consideration in using smartphone-based mobile apps for the management of type 1 diabetes is the cost associated with this type of intervention and their accessibility. Although many of the apps are free or relatively inexpensive, the phone and data service may provide a barrier to care for patients who are unable to afford these extra costs. None of these studies evaluated the cost-effectiveness of mobile apps. In addition, participants enrolled in these studies may be more highly motivated to improve blood sugar control, which adds to selection bias.

Although patients participated in using the mobile apps and the mobile apps plus text messaging/feedback system, there was no method of evaluating to what extent participants actually used these systems.

Diabetes management-related mobile apps from Google Play and Apple apps

As a secondary objective, we evaluated current mobile apps available through both the Google Play Store and Apple App Store. There is a vast array of mobile apps available to support self-management of type 1 diabetes, but most apps are useful only for logging blood sugars and providing data summaries. Some did support the additional features of counting carbohydrates and tracking exercise, but only 11 of 30 provided education concerning at least 1 aspect of diabetes self-management. Future studies could assess the benefit of incorporating patient education in improving self-management skills. However, it is difficult to predict how receptive patients would be to feedback and which types of feedback would be able to elicit improvement in their diabetes self-management skills.

Limitations in the search for mobile apps included the keywords used and the sorting of search results. Patients may use a variety of search terms when they are looking for apps. For the purpose of this study, we aimed to identify a representative selection of the apps available and, therefore, chose 3 sets of keywords that reflect the scope of diabetes self-management, which would include glycemic control (“glucose monitoring”), carbohydrate counting (“carbohydrate counter”), and physical activity (“exercise and diabetes”). McKay et al (28) did a systematic review of mobile apps for health behaviour change and concluded that there is a lack of regulation in health apps. Moreover, although there is an abundance of apps available for type 1 diabetes mellitus self-management, our study shows that only a small number of these apps have been evaluated clinically. Patients need to be cautious when searching for apps to ensure that they are indeed using a reliable app. We based our assessment on the features of the apps in order to make an objective assessment.

Conclusions

Despite a vast array of relatively inexpensive and accessible mobile apps as well as evidence to support their benefit in other chronic diseases, there is a paucity of well-designed studies evaluating the role of these tools in the management of type 1 diabetes. The development and evaluation of more comprehensive mobile apps that allow logging of glucose readings and insulin doses, support carbohydrate counting, incorporate reminders and provide feedback are warranted. This study further highlights the need for larger and longer studies to explore the efficacy of mobile apps for type 1 diabetes that will optimize outcomes, specify the populations that would benefit most from these tools and determine the resources needed to support mobile apps plus text messaging and feedback systems.

Supplementary Material

To access the supplementary material accompanying this article, visit the online version of *Canadian Journal of Diabetes* at <https://www.canadianjournalofdiabetes.com>.

Author Disclosures

Conflicts of interest: None.

Author Contributions

The study was designed by MD, JM and CS, and RS. The literature search was conducted with by RS. Data extraction was conducted by CS, BW and MD. Data analysis and first draft of the manuscript was completed by CS. The manuscript was reviewed and approved by all authors.

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Supplementary Material

Search Strategy

Database: Embase Classic+Embase<1947 to 2018 February 23>, Ovid MEDLINE(R) ALL <1946 to February 23, 2018>, EBM Reviews–Cochrane Central Register of Controlled Trials <January 2018>

Search Strategy:

- 1 diabetes mellitus/ or exp diabetes mellitus, type 1/ or exp diabetes mellitus, type 2/ (1035383)
- 2 [diabet\\$.tw.](#) (1398400)
- 3 (IDDM or NIDDM or MODY or T1DM or T2DM or T1D or T2D).tw. (115788)
- 4 or/1–3 (1592850)
- 5 Mobile Applications/ (7346)
- 6 ((mobile or portable or iphone\$ or ipad\$ or android\$ or blackberry or windows or web) adj3 app\$).tw. (23424)
- 7 cell phones/ (19063)
- 8 ((cell\$ or mobile\$) adj3 (device\$ or phone\$)).tw. (32074)
- 9 (smartphone\$ or smart-phone\$).tw. (15209)
- 10 electronic mail/ or text messaging/ (24197)
- 11 (email\$ or e mail\$ or electronic mail\$).tw. (40854)
- 12 ((text\$ adj3 messag\$) or (sms adj3 messag\$)).tw. (8680)
- 13 [texting.tw.](#) (1451)
- 14 (mobile health or mhealth or m health).tw. (5923)
- 15 (mobile adj3 (communication\$ or telecommunication\$ or telehealth\$ or telemedicine)).tw. (2690)
- 16 health [apps.tw.](#) or apps.ti. (1899)
- 17 Computers, Handheld/ (4472)
- 18 ((handheld or hand-held) adj1 (computer? or pc? or device\$)).tw. (3806)
- 19 (tablet adj3 (device\$ or comput\$)).tw. (2599)
- 20 (tele monitor\$ or telemonitor\$).tw. (3627)
- 21 or/5–20 (132970)
- 22 4 and 21 (5750)
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- 24 *diabetes mellitus/ (294309)
- 25 insulin dependent diabetes mellitus/ (172948)
- 26 *non insulin dependent diabetes mellitus/ (206311)
- 27 [diabet\\$.tw.](#) (1398400)
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- 33 text messaging/ (5415)
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- 35 (smartphone\$ or smart-phone\$).tw. (15209)
- 36 ((text\$ adj3 messag\$) or (sms adj3 messag\$)).tw. (8680)
- 37 e-mail/ (19315)
- 38 (email\$ or e mail\$ or electronic mail\$).tw. (40854)
- 39 [texting.tw.](#) (1451)
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- 54 or/51–53 (1604468)
- 55 Mobile Applications/ (7346)
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- 57 cell phones/ (19063)

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Database: Embase Classic+Embase<1947 to 2018 January 31>, Ovid MEDLINE(R) ALL <1946 to January 31, 2018>
 Search Strategy:

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 35 ((mobile or portable or iphone\$ or ipad\$ or android\$ or blackberry or windows or web) adj3 app\$).tw. (22227)
 36 mobile phone/ (20659)
 37 text messaging/ (4854)
 38 ((cell\$ or mobile\$) adj3 (device\$ or phone\$)).tw. (30469)
 39 (smartphone\$ or smart-phone\$).tw. (14044)
 40 ((text\$ adj3 messag\$) or (sms adj3 messag\$)).tw. (7283)
 41 e-mail/ (18945)

- 42 (email\$ or e mail\$ or electronic mail\$.tw. (39009)
- 43 **texting.tw.** (1319)
- 44 (mobile health or mhealth or m health).tw. (5394)
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- 46 health **apps.tw.** or apps.ti. (1830)
- 47 *microcomputer/ (13321)
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- 55 53 and 54 (553)
- 56 **55 use emczd (553) Embase**
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- 58 remove duplicates from 57 (699)
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- 60 **58 use medall (230) Embase**