REVIEW

Smartphone-Based Technology in Diabetes Management

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ABSTRACT

Diabetes is a group of metabolic disorders characterized by elevated levels of blood glucose which leads over time to serious complications and significant morbidity and mortality worldwide. Self-management tasks in diabetes may be quite challenging because of lack of training, difficulties in sustaining lifestyle modifications, and limited access to specialized healthcare. Nowadays, the evolution of mobile technology provides a large number of health-related smartphone applications (apps), aiming to increase the self-management skills of the patient in chronic diseases, to facilitate the communication between the patient and healthcare providers, and to increase also the patient's compliance with the treatment. In the field of diabetes there are also many diabetes-related mobile apps mainly focusing on self-management of diabetes, lifestyle modification, and medication adherence motivation. The aim of this paper is to review the most important diabetes-related mobile smartphone applications, including only those supported by prospective randomized controlled trials.

Keywords: Diabetes management; Mobile apps; Technology

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Key Summary Points

Self-management tasks in diabetes may be quite challenging because of lack of training, difficulties in sustaining lifestyle modifications, and limited access to specialized healthcare.

The evolution of mobile technology nowadays provides a large number of health-related smartphone applications.

In the field of diabetes many mobile apps are mainly focusing on self-management, lifestyle modification, and medication adherence motivation.

The aim of this paper is to review the most important diabetes-related mobile smartphone applications, including only those supported by prospective randomized controlled trials.

INTRODUCTION

Diabetes is a chronic, metabolic disease characterized by elevated levels of blood glucose leading overtime to microvascular and macrovascular complications [1]. The main types of diabetes include type 1 diabetes, which is caused by an autoimmune β-cell destruction, leading to absolute insulin deficiency; type 2 diabetes caused by a progressive loss of β-cell insulin secretion on the background of insulin resistance; and gestational diabetes that is typically diagnosed during the second or third trimester of pregnancy [2]. Less common types of diabetes include monogenic diabetes syndromes (neonatal diabetes, maturity-onset diabetes of the young), diabetes due to diseases of the exocrine pancreas (cystic fibrosis, pancreatitis), and drug- or chemical-induced diabetes [2].

In 2017 the number of adults with diabetes was approximately 425 million (20–79 years) globally. According to the International

Diabetes Federation (IDF), this number will rise to 629 million by 2045 [3].

Today, it is generally accepted that lifestyle intervention is a fundamental consideration in the treatment of diabetes, including individualized lifestyle plans of diet, exercise, and weight management [4].

Advances in digital technology and especially mobile smartphone technology have led to a plethora of innovative strategies aiming to improve the self-management skills of patients with chronic diseases and especially diabetes. Recently, in 2011, the World Health Organization (WHO) proposed a definition for mobile health (mHealth)—a component of eHealth—as the "medical and public health practice supported by mobile devices" [5]. Over the last decade, mHealth technology utilization has increased access to health-related information for both patients and healthcare providers and also facilitating remote patient monitoring [6].

Today, more than 100,000 health-related applications are available in the Apple App Store (iOS operating system; Apple Inc.) and Google Play Store (Android operating system; Google), reflecting a rapidly increasing market that may potentially transform the traditional healthcare scheme, providing a large number of useful tools for patients and healthcare providers [7, 8].

Diabetes is the most popular chronic clinical condition targeted by mHealth, followed by depression and asthma. A progressively increasing number of medical applications have recently emerged to cover the needs of patients with diabetes [9]. Most of them provide mainly diabetes consultation and telemanagement services. Diabetes telemanagement services enable healthcare providers to distantly follow up their patients, providing also treatment recommendations. Advisory services are mainly aimed at increasing the self-management skills of the patient, by storing personal data, such as glucose, hemoglobin A1c or glycated hemoglobin (HbA1c), blood pressure, body weight etc., and facilitating them in taking treatment decisions, by utilizing pre-stored validated algorithms.

In 2017, more than 1500 diabetes-related apps were reported to be available for users. In 2015, 70% of mHealth practitioners reported

that diabetes is currently the leading health target for the mobile app industry [10].

For this review we searched for relevant English-language papers in Pubmed and Google Scholar using the terms diabetes self-management, eHealth, mHealth, smartphone applications, and randomized clinical trials during the period from May 2011 to May 2019. The aim of this manuscript is to review the most important diabetes [type 1 diabetes mellitus (T1DM) and type 2 diabetes mellitus (T2DM)]-related mobile apps, including only those supported by prospective randomized controlled trials. This article is based on previously conducted studies and does not involve any new studies of human or animal subjects performed by any of the authors.

APPLICATIONS FOR PATIENTS WITH T1DM

Although a large number of diabetes management apps are available, only a few of them are designed to assist patients with T1DM in calculating their insulin dose, thereby simplifying this everyday decision-making process [11].

Many applications for Android and Apple devices claim to perform all the necessary calculations; however, the vast majority of them have not been approved by the US Food and Drug Administration (FDA) or other corresponding regulatory authorities. The following section describes the latest smartphone insulin dose calculator applications tested in randomized clinical trials [12]. All data considering T1DM apps and the relevant studies are summarized in Table 1.

Intelligent Diabetes Management (IDM), University of Alberta

Intelligent Diabetes Management (IDM) is a smartphone application for patients with type 1 diabetes developed by the University of Alberta and launched in 2014. This application includes a glucose and meal tracker, providing a detailed record in a diary format. Data can be viewed on the linked IDM website (https://idm.ualberta.

ca) and can be formatted to present insulin dose, planned physical activity, carbohydrate intake, hypoglycemia, etc. This application also provides a summary snapshot of the median values of blood glucose from meal to meal and overnight. This layout along with the bolus calculator wizard helps the patient to make adjustments in insulin dose in a convenient and user-friendly way [13].

In a randomized controlled trial by Ryan et al., the IDM group presented a significant improvement of the median A1c level from 8.1% (IQR 7.5–9.0) to 7.8% (6.9–8.3; $p < 0.001$). It is noteworthy that during the study observation period, the review of the glucose diaries on the IDM website was faster compared to the review of the traditional personal glucose records (median 6 min compared to median 10 min; $p < 0.05$) [13].

Glucose Buddy

The application Glucose Buddy is another diabetes-related app that allows the users to manually enter their blood glucose readings along with notes and details about their meals. In addition, users may also enter their carbohydrate consumption, insulin dosage, and physical activity. Using the graph function, users may easily track their blood glucose levels over a selected time period [14].

The user of this app may detect glucose trends, using the convenient and user-friendly graphs showing data for 7, 14, or 30 days. In addition, the meal and the physical activity recording option is tedious and laborious for the average user. Finally, the patient may also record carbohydrate consumption as well as other nutritional entities such as fat, salt, and fiber [14].

Recently, in a multicenter randomized clinical trial by Rhyner et al. it was reported that Glucose Buddy calculates the carbohydrate content of meals with higher accuracy compared with the standard method. The mean absolute error was 27.89 (SD 38.20) g of carbohydrate for the estimation of the participants, whereas the corresponding value for the Glucose Buddy estimation was 12.28 (SD 9.56) g of

Table 1 Apps for patients with T1DM

Application name	Study country	Type of study	Randomized clinical trial (participants who completed the study/control group)	Maximum duration of follow-up (months)	Study summary and status
Intelligent Diabetes Management	Ryan et al. [13]/ Canada	Single center (mainly) 28/31 initial participants were from the local university hospital clinic	18/10	4	Significant improvement of the median HbA1c levels Faster review of glucose records
Glucose Buddy	Rhyner et al. [16]/ Australia	Multicenter	53/28	9	Weekly text message support from a healthcare professional No significant change over time was found in either group in relation to self-efficacy, self-care activities, and quality of life
Diabetes Manager	Garg et al. [17]	Single center	100/50	6	Statistically significant decrease in HbA1c levels without increasing the risk for hypoglycemia
Diabetes Diary	Skrøvseth et al. [18]/ Norway	Single center	30/15	3	No statistically significant difference in HbA1c levels between groups
Dbees	Drion et al. [20]/ Netherlands	Single center	63/32	3	No statistically significant change in quality of life
Diabetes Interactive Diary	Rossi et al. [21]/Italy	Multicenter	127/64	6	Significant decrease of HbA1c levels. Lower hypoglycemia event rates. Improvement in treatment satisfaction and several quality of life aspects
D-Partner	Doupis et al. [22]/Greece	Single center	24/12	3	Significant decrease of HbA1c levels. Decrease of hypoglycemia rate
GoCARB	Rhyner et al. [16]/ Switzerland	Single center	19/8	0.3	Better carbohydrate counting compared with standard care

Table 1 continued

Application name	Study country	Type of study	Randomized clinical trial (participants who completed the study/control group)	Maximum duration of follow-up (months)	Study summary and status
VoiceDiab	Foltynski et al. [24]/ Poland	Single center (crossover)	44/22	9	Improvement of postprandial glucose control without increasing hyperglycemia or hypoglycemia rates

carbohydrate, which was a significantly better performance ($p = 0.001$). In addition, the participants evaluated the app as a useful and easy-to-use tool for diabetes management making Glucose Buddy a well-accepted supportive mobile health (mHealth) tool for the assessment of served-on-a-plate meals [14–16].

Diabetes Manager

Diabetes Manager is an all-in-one app that includes an insulin calculator, a carbohydrate database, a favorites database, and a diary. It is developed for patients with T1DM mainly to assist them with the pre-meal insulin dose calculation. This app is only available in the Apple Store for iOS devices.

In 2017, Garg et al. conducted a single-center randomized clinical trial using an integrated iBGStar system (a blood glucose meter) attached to an iPhone mobile phone device on which Diabetes Manager was installed. The aim of the study was to provide intensive monitoring of blood glucose utilizing the capabilities of a mobile phone device. The results of the study documented a significant decrease in HbA1c value after 6 months of intervention in the Diabetes Manager group compared to the control group (-0.16 vs -0.51, $p = 0.04$). In addition, the hypoglycemia fear (measured by patient-reported outcome, PRO) was improved in both groups at 6 months (-1.4 ± 10.0 vs -3.9 ± 12.5, $p = 0.32$). Thus, the use of the Diabetes Manager mobile app, over a 6-month follow-up, resulted in a significant

improvement of glycemic control, compared to the control group, without increasing the risk for hypoglycemia [17].

Diabetes Diary

Diabetes Diary is a self-management tool for patients with diabetes, developed by the Norwegian Center for e-health Research (NSE) in Tromsø, Norway. It was designed to enable the patients to record blood glucose, insulin, carbohydrates, and physical activity. Additionally, a data-driven feedback module Diastat was designed and based on data from a preceding randomized trial by NSE.

In a recent study, 30 patients with type 1 diabetes were randomized to use Diabetes Diary in two groups. Using a stepped-wedge design, both groups initially used the Diabetes Diary application without the Diastat module. Group 1 activated Diastat 4 weeks after the baseline visit, whereas group 2 activated Diastat 12 weeks after the baseline visit (T1). The endpoints of the study were the HbA1c level and number of out-of-range (OOR) measurements [18].

The study results proved no significant difference between groups at T1 in HbA1c or OOR events. Overall, all patients presented a decrease of 0.6% in mean HbA1c ($p < 0.001$) and 14.5 in median OOR events over 2 weeks ($p < 0.001$) [18].

Dbees

Diabetes under Control (dbees) is another mobile application in the field of T1DM self-

management that provides a detailed diary and also enables a secure data connection with healthcare providers [19]. In 2015, Drion et al. included dbees as a part of a randomized controlled open-label trial measuring the effects of this app on the quality of life (QOL) in 63 patients with T1DM. In this study, 32 patients were randomized to use the standard paper diary (control group), whereas 31 were randomized to use the dbees app. In addition, changes in QOL were measured by the RAND-36 questionnaire. No significant difference in the QOL, was reported within and between the two groups after 3 months of intervention. Glycemic control, diabetes-related emotional distress, and frequency of self-monitoring of blood glucose remained unaffected in both groups and without significant differences between the groups. In addition, users evaluated the usability of dbees with a median 72 ± 20, on a scale of 0–100. In summary, the results of this study reported no significant change in QOL after a 3 month use of the dbees application compared with the use of a standard paper diary [20].

Diabetes Interactive Diary (DID)

The Diabetes Interactive Diary app incorporates multiple capabilities as an automatic carbohydrate and insulin bolus calculator, an information technology, as well as a telemedicine tool. It allows real-time communication between healthcare professionals and patients via short text messages. Furthermore, it provides a smart wizard for planning a flexible diet and calculating the matching insulin bolus for meals [21].

In an open-label, multinational, multicenter randomized controlled trial conducted by Rossi et al. in 2013, DID was compared with standard carbohydrate counting practice in terms of metabolic and weight control, quality of life, diabetes education requirements, and treatment satisfaction in a 6-month follow-up. The study included 127 patients with type 1 diabetes (age 36.9 ± 10.5 years; diabetes duration 16.3 ± 9.3 years). HbA1c levels decreased by $0.49 \pm 0.11\%$ in the intervention group and $0.48 \pm 0.11\%$ in the control group ($p = 0.73$). It is noteworthy that there was a 86% lower risk of

grade 2 hypoglycemia (defined as hypoglycemia requiring third-person assistance) in the intervention group compared to the control group. DID was at least as effective as traditional carbohydrate counting education, allowing dietary freedom to a larger proportion of patients with T1DM. DID is safe, requires less time for education, and is associated with lower weight gain. DID also significantly improved treatment satisfaction and several quality of life aspects [21].

D-Partner

D-Partner (Diabetes Innovations Ltd.) is a mobile-based application that serves as a self-management tool for type 1 diabetes, including a bolus wizard (with food database), a basal insulin titration manager, as well as a large number of automated notifications, warnings or reward messages, as a response to the data imported by the patient. In addition, D-Partner serves as a telemedicine tool, as all the imported data including glucose measurements, meal composition, insulin dosage, blood pressure, body weight, exercise and lab values may be monitored by the physician through an on-line, web-based platform [22].

In a single-center randomized clinical trial, D-Partner was compared with standard of care in a group of 24 patients with type 1 diabetes and inadequate glucose control. The mean age of the participants was 37.4 ± 11 years, and the mean duration of diabetes was 14.2 ± 8.8 years. The intervention group presented a significant reduction of the HbA1c at 3 months after the baseline visit, compared to the control group ($p = 0.01$). Additionally, hypoglycemia rate (defined as the number of cases of verified hypoglycemia per week) was significantly lower in the intervention group ($p = 0.04$), whereas there were no significant changes in somatometric data, blood pressure, and heart rate between the two groups [22].

GoCARB

GoCARB is a new application aiming to support patients with type 1 diabetes in more accurate carbohydrate counting. The system runs on

Table 2 Apps for patients with T2DM

Application name	Authors and country of study	Type of study	Randomized clinical trial (participants who completed the study/control group)	Maximum duration of follow up (months)	Study summary and status
Diabeo	Charpentier et al. [26]/ France (Telediab 1)	Randomized, open-label, parallel-group, multicenter trial	G1 ($n = 61$) G2 ($n = 60$) G3 ($n = 59$)	6	Diabeo and teleconsultation group presented significant improvement in HbA1c by 0.91%, while the group G2 with Diabeo and hospital visits presented a 0.67% improvement. Hypoglycemia rates did not differ among the groups
	Franc et al. [28]/France (Telediab 2)	Randomized, controlled, open-label, multicenter study	G1 ($n = 63$) G2 ($n = 64$) G3 ($n = 64$)	13	Diabeo users presented a significant improvement in HbA1c without increasing severe hypoglycemic event rates
	Jeandidier et al. [27]/ France (Telesage)	Multicenter, double-randomized, open-label, three-parallel-arm study	$n = 696$	–	Three groups. A control group (standard care), a group using Diabeo, assisted by a physician, and another group using Diabeo assisted by a delegated nurse
					HbA1c level is the primary endpoint of the study. Expected to confirm the previous results of the Telediab 1 and 2 studies on a larger sample of patients
					Evaluate a nurse-assisted telemonitoring system. Assess utility and efficacy of Diabeo telemedicine
					Status: ongoing
Diabetes Pal	Bee et al. [29]/ Singapore	Randomized, open-label, parallel-group trial	33/33	6	No statistically significant difference between the two groups in HbA1c
					No episodes of severe hypoglycemia were recorded

Table 2 continued

Application name	Authors and country of study	Type of study	Randomized clinical trial (participants who completed the study/control group)	Maximum duration of follow up (months)	Study summary and status
BlueStar	Agarwal et al. [30]/ Canada	Multicenter randomized controlled trial	110/113	6	HbA1c levels did not show evidence of reduction No effect was proven on diabetes self-management, quality of life, and healthcare utilization behaviors
Bant2	Goyal et al. [33]/ Canada	Prospective, multicenter randomized controlled study	75/75	12	The study examines the effect of the bant2 app on HbA1c levels, blood pressure, weight, total cholesterol, LDL cholesterol, weight at baseline, 3, 6, 9, and 12 months along with its effect on self-management and lifestyle Status: ongoing

Android mobile phones and uses computer vision technology to estimate the carbohydrate content of meals. For each estimation, the user places a reference card next to the meal and acquires two images using the camera of the mobile phone. The images are then sent to a dedicated server via Wi-Fi or the mobile network, where a series of computer vision operations are performed. All computer vision modules run on the server, whereas the mobile phone is used for three specific steps: image acquisition, carbohydrate calculation, and visualization of the results.

GoCARB was evaluated by Rhyner et al. in a 10-day trial at the Bern University Hospital. Nineteen adult volunteers with type 1 diabetes participated in the study. During the study, a total of six mixed meals were provided from the hospital's restaurant to the participants every day [16]. The food items were weighed and the amount of carbohydrates was calculated using the US Department of Agriculture (USDA) nutrient database as a standard reference method [23]. Participants were requested to count the carbohydrate content of each meal first with the standard method and then by using GoCARB. At the end of each session, a questionnaire was completed to evaluate the user's experience with GoCARB. The results of this study indicate that GoCARB enabled the patients to calculate the carbohydrate content of meals with higher accuracy compared to the standard method. It is also noteworthy that the majority of the participants reported that the application was useful and easy to use [16].

VoiceDiab

VoiceDiab is a client–server system enabling the patient to calculate meal insulin dose on the basis of the voice description of the meal content. The system includes an Android-controlled smartphone with the client application

installed, and a set of three servers responsible for automatic speech recognition (ASR) and transformation of the verbal description of meals into text, followed by a text analysis of the meal's description to determine its composition, and finally a calculation of the insulin dose required for the meal [24].

VoiceDiab was tested in a randomized crossover clinical trial by Foltynski et al. on 44 patients with type 1 diabetes, treated with continuous subcutaneous insulin infusion. The participants were randomly divided into two groups. The intervention group, in which bolus calculation was supported by the VoiceDiab system, and the "unsupported" control group, in which patients calculated boluses with a standard method. After a 14-day washout period, patients from the supported group were switched to the unsupported group, and vice versa. The results of the study showed a significant improvement of the "on-target" rate of postprandial glycemia with the use of Voice-Diab versus standard care (58.6% vs 46.6%, respectively; $p = 0.031$). Thus, VoiceDiab may be a useful tool for improving postprandial glucose control, without increasing hyperglycemia or hypoglycemia rates in patients on intensive insulin therapy [25].

TYPE 2 DIABETES MOBILE APPS

Today the number of people with T2DM is increasing globally with extremely high rates. This type of diabetes is much more frequent than type 1 diabetes and presents most often in adults. Treatment of T2DM combines lifestyle changes, followed by oral and subcutaneous antihyperglycemic agents as well as insulin. All data considering T2DM apps and the equivalent studies are summarized in Table 2.

Diabeo

The Diabeo app is a CE-marked medical device in Europe that can be used on a mobile phone with an Android or iOS operating system, or on a web portal accessed through any web browser. It has been designed for adults with type 1 or type 2 diabetes on insulin therapy, allowing the patient to record blood glucose levels, insulin doses, physical activity, carbohydrate intake, and hypoglycemia. It serves as a self-management tool, processing data and calculating bolus insulin dosages according to carbohydrate intake. Furthermore, it provides a basal adjustment algorithm along with educational messages. The Diabeo system also provides a multi-patient dashboard for healthcare professionals, allowing remote patient management [26, 27].

The Telediab 1 study was a 6-month, open-label, three-arm, parallel-group, multicenter study in a group of 180 adult patients with type 1 diabetes, on a basal–bolus insulin regimen, with HbA(1c) $\geq$ 8%. The first arm (G1) received standard of care, the second arm (G2) used Diabeo for insulin dose calculation with regular hospital visits every 3 months, while the third arm (G3) used Diabeo with short teleconsultations every 2 weeks and no hospital visits. After 6 months, the mean HbA1c in group G2 was $8.63 \pm 1.07\%$, in group G3 it was $8.41 \pm 1.04\%$, and in group G1 it was $9.10 \pm 1.16\%$; $p = 0.0019$. The Diabeo and teleconsultation group presented a significant benefit with a 0.91% (0.60; 1.21) improvement in HbA1c, while the group with Diabeo and hospital visits had a 0.67% (0.35; 0.99) improvement. Hypoglycemia rates did not differ among the three groups [26].

The Telediab 2 trial was another randomized, controlled, open-label 13-month study conducted in subjects with inadequately controlled T2D from 18 French hospitals between December 2008 and January 2012. In this study 191 patients were randomized in three groups: group G1 ($n = 63$) received standard care, group G2 ($n = 64$) used an interactive voice response system, while group G3 ($n = 64$) used Diabeo-BI. Patients in groups G2 and G3 received daily adjustments of basal insulin dose. After a 4-month intervention, groups G2 and G3 presented a significant improvement in HbA1c: group G2 presented a 1.44% reduction in HbA1c, while groups G3 and G4 presented a 1.48% and a 0.92% reduction, respectively ($p < 0.002$). No severe hypoglycemic events were reported in groups G2 and G3 [28].

Finally, Telesage is an ongoing multicenter, double-randomized, open-label, three-parallel-

arm study, in approximately 100 centers in France. The study ($n = 696$) compares a control group (standard care), a group using Diabeo, assisted by a physician, and another group using Diabeo assisted by a delegated nurse. HbA1c levels are the primary endpoint of the study; thus, the Telesage study is expected to confirm the previous results of the Telediab 1 study on a larger sample of patients. It is also expected to evaluate a nurse-assisted telemonitoring system. Eventually, the Telesage study will also assess the potential of the Diabeo telemedicine service in terms of its utility and efficacy. The study is in progress and the official results are not yet published [27].

Diabetes Pal

Diabetes Pal is an app designed for patients with type 2 diabetes and it is available for both Android and iOS mobile devices. It enables the user to either monitor their blood glucose measurements directly from their glucose meter via Bluetooth or manually by inserting the glucose measurements into the app.

The app also enables healthcare professionals to track the patients' glucose measurements, thus serving as a telehealth tool. It also provides text instructions to counter hypoglycemic events. Data such as lifestyle, physical activity, hypoglycemic episodes, caloric intake, and body weight are not monitored [12].

A 24-week, randomized, open-label, parallel-group trial was conducted at the Singapore General Hospital on a group of 66 insulin-naive patients with type 2 diabetes. All patients received instructions, on insulin titration and blood glucose monitoring, from a diabetes nurse educator and they were randomized into a control group and an intervention group. Patients in the control group ($n = 33$) used logbooks and written text instructions, while patients in the intervention group ($n = 33$) entered fasting blood glucose levels into the app daily and the app recommended a suitable insulin dose. The mean baseline HbA1c of the patients was $9.9 \pm 1.8\%$. During the study, there was an average drop from 9.9% to 8.8% after 6 weeks and to 8.2% after 12 weeks, with

no statistically significant difference between the two groups ($p = 0.88$). Finally, it is noteworthy that no episodes of severe hypoglycemia were recorded [29].

BlueStar

BlueStar is an in-app diabetes coach available for Android and iOS devices. This was the first mobile app in the USA to be given FDA approval as a mobile prescription therapy [30]. In the BlueStar app, patients can enter their blood glucose levels (wirelessly or manually) and receive real-time coaching. They can also organize their medication plan and get advice on their lifestyle and diet. Variables such as blood pressure and body weight are also integrated. Moreover, patients may receive more than 25,000 automated coaching messages, personalized education, and they can share their health status with their healthcare team [31].

In a randomized multicenter controlled trial with 110 participants in the immediate treatment group (ITG), who used the app for 6 months, and with 113 in the wait-list control (WLC) group, who received usual care for the first 3 months and then used the app for the last 3 months of the study, HbA1c levels did not show evidence of reduction at 3 months (mean difference [ITG − WLC] − 0.42, 95% CI − 1.05 to 0.21; $p = 0.19$). Additionally, no effect was proven on diabetes self-management, quality of life, and healthcare utilization behaviors [30]. Older studies had shown significant HbA1c reduction [32] and improvement in self-efficacy [31].

Bant2

Bant2 is a smartphone app designed for Android and iOS devices that connect to peripheral devices, enabling the patient to store data related to daily food intake, body weight, blood glucose, and HbA1c [12].

A 12-month, prospective, multicenter randomized controlled study in a group of 150 non-insulin-treated patients with type 2 diabetes and HbA1c > 7.5% started in 2015 and is still ongoing. According to the design of the

study, the control group ($n = 75$) receives standard of care, while the intervention group receives standard of care plus the use of the bant2 app. The study examines the effect of bant2 on HbA1c levels, blood pressure, weight, total cholesterol, LDL cholesterol, weight at baseline, 3, 6, 9, and 12 months along with its effect on self-management and lifestyle [33, 34].

DISCUSSION

Undoubtedly, the proliferation of mobile medical apps targeting diabetes self-management is showing the vital need for ameliorated methods to address poor rates of behavioral adherence in diabetic patients [35].

Although the vast number of commercially available diabetes self-management apps have varying uses and contents, only a small percentage of them were evaluated in clinical trials for safety and efficacy. Hence, given the limited existing evidence, it would be frivolous to compare the efficacy of the different diabetes management-related mobile apps.

Furthermore, novel mobile apps should aim to initiate behavior changes and treatment adjustments in a positive way for both clinical outcomes and quality of life, considering that diabetes is a chronic and complicated disease in which glycemic management alone may not be enough to improve health outcomes.

Our manuscript is a narrative literature review of data from two validated medical research databases, PubMed and Google Scholar, including only English-language papers on prospective randomized clinical trials on smartphone applications for T1DM and T2DM management from May 2011 to May 2019. Most of the studies reviewed in this paper were single-center trials evaluating short-term outcomes of the examined mobile apps. Undoubtedly, more randomized controlled trials with longer follow-up period should be conducted to evaluate the long-term effect of the diabetes-related mobile apps on glucose control and life quality, and to confirm that the outcomes seen in initial studies are sustainable over time.

CONCLUSIONS

Over the last decade a plethora of mobile medical applications have become available to patients with diabetes, on various platforms and devices. In general, the vast majority of the applications available on the market integrate a basal or/and bolus insulin management tool, automated feedback based on blood glucose pattern analysis, and a secure data-sharing system with other healthcare professionals.

So far, regardless of the limitations of the available studies, most of the reviewed mobile medical applications have been shown to positively effect outcomes, including HbA1c levels and hypoglycemia rates. Giving that, today, the need for individualized care for patients with diabetes is more evident that ever, a validated evidence-based guidance should be established for the selection of the most suitable mobile-based diabetes app. Hence, guidelines from scientific organizations and authorities in the field of mobile health are also necessary.

Mobile health is a major and promising area of continued development for the self-management of diabetes. Thus, further long-term, multicenter studies are necessary to prove the long-term impact of the available applications, while the continuing efforts should target the development of the ideal smartphone-based self-management tool for diabetes.

ACKNOWLEDGEMENTS

Festas, Christos Tsilivigos, Vasiliki Efthymiou, and Alexander Kokkinos have nothing to disclose.

Compliance with Ethics Guidelines. This article is based on previously conducted studies and does not involve any new studies of human or animal subjects performed by any of the authors.

Data Availability. Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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