

# Innovative health informatics as an effective modern strategy in diabetes management: a critical review

S. K. David,<sup>1</sup> M. R. M. Rafiullah<sup>2</sup>

<sup>1</sup>Department of Information Technology, Strategic Center for Diabetes Research, King Saud University, Riyadh, Kingdom of Saudi Arabia

<sup>2</sup>Department of Pharmacology, Strategic Center for Diabetes Research, King Saud University, Riyadh, Kingdom of Saudi Arabia

## Correspondence to:

Satish Kumar David,  
Department of Information Technology, Strategic Center for Diabetes Research, King Saud University, Riyadh, Kingdom of Saudi Arabia  
Tel.: + 966 11 4724179 X 3700  
Fax: + 966 11 4725682  
Email: skumar@ksu.edu.sa

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None.

## SUMMARY

**Objective:** Diabetes mellitus is the most common metabolic disorder in developing countries. Mobile health applications are helpful in improving the diabetes management. However, the effectiveness of these techniques needs to be assessed rigorously. Therefore, the authors have systematically reviewed the recent clinical studies using mobile health applications for diabetes management. **Materials and methods:** Original articles that were published in ISI indexed journals listed in PubMed from the year 2007 till 2014 were searched using specific search key phrases. The intervention technology and study methodology were analysed to have a better understanding of the outcomes of each study. **Results:** Twenty-one articles were selected for the review. Most studies (76%) reported positive outcomes after use of the mobile health applications. Smartphone apps significantly improved the clinical outcomes. User-friendliness of the systems often influence the patient compliance and the clinical outcomes. **Conclusion:** Smartphone/web applications offer significant benefits for patient care, education and behavioural modifications. Providing a continuous patient support using mobile may be a challenging task and would require adequate infrastructure and personnel.

## Review criteria

Using specific key phrases 'clinical study on use of mobile phones/smartphones/cell phones/mobile applications for diabetes' original articles that were published between 2007 to 2014 in ISI indexed journals from PubMed database were gathered. The articles were analyzed by classifying them into mobile applications for diabetes management, patient education and patient behavior modifications.

## Message for the clinic

Web based tools have shown very good effect on diabetic patient management and education but had limited behavioral modification role. Phone calls are becoming less popular and only two studies that have been used for behavioral modification with good outcome. The text messages were effective, but Smartphone Apps and teleconsultation techniques fared better in the clinical outcomes.

## Introduction

Diabetes mellitus is considered to be the most common chronic disease affecting human beings as reported by the International Diabetes Federation with more than 366 million people currently affected and is expected to reach 552 million by the year 2030. The high mortality and morbidity as a result of chronic complications which make diabetes the leading cause of blindness, renal failure, ischaemic heart disease and limb amputation (1). Diabetes mellitus is considered to be costly disease in terms of economic burden, since the healthcare expenditure for diabetes in USA during 2011 was 7.7 billion US dollars with direct costs of 3.4 billion US dollars and indirect costs of 4.3 US dollars (2).

Diabetes is growing in pandemic proportion that needs to be addressed in every possible way to contain its growth through awareness, education and implements that enable self-management of the disease by patients. In this aspect, information technology (IT) together with mobile handsets can play a pivotal role in facilitating dissemination of information and hence help better management of the disease.

The huge developments and advances in mobile phone technology and its applications coupled with equally robust growth of telecommunication technology can serve to give patients a better access to healthcare information, which can make their life easier and enable efficient self-care. eHealth services that continue to grow rapidly worldwide can also make web-based health services easier, quicker, accurate and cost effective. In effect, the ever-expanding computing ability of smartphone's together with the increasing footprint of the communication network, and the ever pervasive IT can be exploited to bring healthcare services to the patient's doorstep. Mobile technology can be used by both the healthcare service providers and the patients equally (3). For example, doctors are adopting smartphone apps to seek clinical knowledge and case studies, while patients are utilising the same to have access to health information that will improve their understanding and management of their diseases (4,5).

The rate by which mobile technology is growing is something that cannot be overlooked, for example, a recent study has shown that there will be 11.5 billion mobile connected devices on use worldwide and the

global mobile data traffic will increase 10 times by the year 2019 (6). Thus, the healthcare delivery can ride on this growth to reach the customers with healthcare solution. As smartphones becoming ubiquitous and being increasingly used for medical application such as disease management, it is necessary to evaluate their effect and role in the medical health system (7,8). In the year 2011, there had been more than 44 million healthcare apps downloaded globally and more than 40,000 generic (non-healthcare) mobile apps were available. About 12,000 apps were offered through Apple iTunes store alone (9,10).

An analysis of these healthcare apps reveals that most of the apps are targeted to non-professionals, i.e. general public and patients while some of the apps focus on medical professionals namely doctors, nurses and other paramedics. Those apps have wide range of functionality from simple software educational programmes to complicated high technology systems such as blood pressure (BP) monitor, blood glucose analyser, activity monitor, etc. (11).

Healthcare providers and patients expressed satisfaction over the use of these healthcare apps owing to the increased data accessibility, and reasonable effectiveness on patient health. Endocrine disease focused apps are currently found in different platforms namely Android or Apple iOS (12).

Research evidence suggests that mobile apps are a good option in tackling issues related to diet, treatment adherence and weight management especially in diabetes mellitus. Although many of healthcare apps have proved to be helpful in improving patient's clinical profile and reduce complications associated with diabetes mellitus, the effectiveness of these and other newer methods remains to be evaluated. Therefore, this systematic review is an attempt to review and assess recent clinical studies using innovative health informatics systems like smartphone health applications for management of diabetes mellitus.

## Methods

This study intended to evaluate the effectiveness of mobile health applications in management of diabetes mellitus using original articles that were published in ISI indexed journals from PubMed database.

A total of 209 scientific articles were captured from the PubMed database starting by the year 2007 till 2014. The search key phrases were 'clinical study on use of mobile phones for diabetes', 'clinical study on use of smartphones for diabetes', 'clinical study on use of cell phones for diabetes' and 'clinical study on use of mobile applications for diabetes'. The search resulted in 66, 64, 62 and 17 articles respectively.

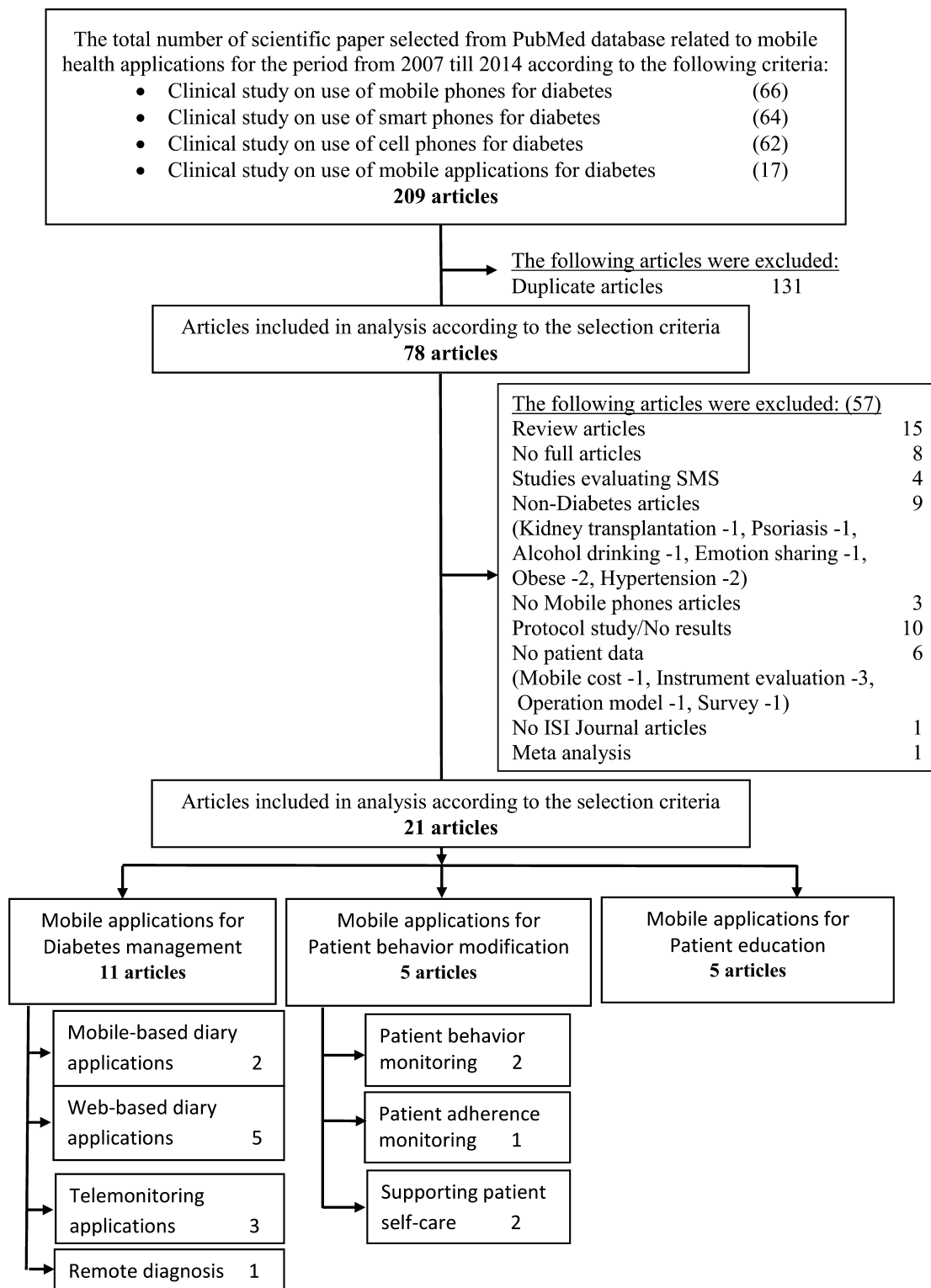
From these 209 articles, 131 were found to be duplicate. Figure 1 shows that out of the remaining 78 articles, only 21 fulfilled our selection criteria. The selection criteria was original articles that reported clinical studies evaluating mobile apps in diabetes patients. These studies were reported from several countries including France (13), UK (14–16), Italy (17), Canada (18), USA (19–24), South Korea (25–29), Taiwan (30), Norway (31), Australia (32) and Austria (33). Patients were recruited from primary and tertiary hospitals and community settings. The excluded 57 articles comprised of 15 review articles, 10 articles with no clear results, nine articles for not being diabetes related, eight articles with insufficient information, six articles for lacking patient data, three articles with no mobile application, one published in non-ISI journal, one meta-analysis and four articles that evaluated the effect of short messaging service (SMS) as primary intervention.

The following information was collected from each article: type, duration of the study, sample size, age, type of diabetes, technology used, aim of the study, methodology and outcome of the study. The technology used and methodology were analysed to have better understanding of the outcome of each study.

Table 1 shows the study which classified the reviewed original papers into 'mobile applications for diabetes management' which included any applications related to diabetes management. Table 2 shows the second group which comprised of the articles related to 'mobile applications for patient education' which included all the articles, where smartphone was used as a tool for health education. Table 3 shows the third group 'mobile applications for patient behaviour modifications' which included studies that looked into mobile applications which would affect and contribute to behaviour changes.

## Results and discussion

Chronic diseases such as diabetes need self-management by patients to achieve stable control of the disease. Diabetes management is often cumbersome and demanding, as it requires the patients to do regular home-based glucose monitoring and apply continuous lifestyle modifications. Typical diabetes management plans always include diabetes education and regular follow-up of patients to achieve the treatment goals. Evolvement of mobile phones and their wide reach has paved way for development of various mobile health applications. This has attracted a lot of attention from diabetes healthcare researchers as it aptly suits for implementing various aspects of diabetes management plans such as patient remote



**Figure 1** Flow diagram for the scientific paper selection from the PubMed database

monitoring, data collection, patient education and medical intervention. The articles reviewed in the present paper have evaluated various mobile health interventions that were aimed to achieve diabetes

management, patient education and patient behaviour monitoring.

The selected 21 articles were then classified into 11 articles related to mobile applications for diabetes

**Table 1** Mobile applications for diabetes management

Sl.	Title of the article	Types of study/duration	Sample size/type of diabetes/mean age (years)	Technology used	Aim of the study	Methodology	Outcome	References
1	Telemedicine-supported insulin optimisation in primary care	Feasibility study/ 6 months	23 Type 2 diabetes mellitus/ 57.6	Website	To investigate the feasibility of insulin dose adjustment using a mobile-phone-based diary for improving HbA1c	Patients were provided with a mobile phone diary and a Bluetooth connected glucometer. Patients were instructed to measure their fasting blood glucose to adjust their insulin dose using a self-titration algorithm. A specialist diabetes nurse reviewed the patients' data every 2 or 3 days using a secure website	There was a significant mean decrease in HbA1c, while the mean insulin dose increased. Blood glucose monitoring compliance was found to be high	Larsen et al. (15)
2	Interactive diary for diabetes: A useful and easy-to-use new telemedicine system to support the decision-making process in type 1 diabetes	Pilot study (cohort study)/ 9 months	41 Type 1 diabetes mellitus/ 31.6	Smartphone application called DID and SMS	To investigate whether DID app could be used in the management of type 1 diabetes for effective metabolic control	Patients were given mobile phones with diabetes interactive diary (DID) programme set up. This enabled the patients to record glucose values, total CHO intake and the system suggested the insulin bolus doses. It also allowed the patients to send the data to physician through SMS	HbA1c, FBG and PPG levels were decreased but were not found to be significant. The coefficient of variation for FBG and PPG was significantly lesser, indicating a decreased fluctuation. All the patients considered the system very easy to use and helpful	Rossi et al. (17)
3	Qualitative evaluation of a mobile phone and web-based collaborative care intervention for patients with type 2 diabetes	Randomised control trials/ 3 months	14 Type 2 diabetes mellitus/ 18–75 years	Web-based programme, Videogame console and Mobile	To assess the patient feedback on the usage of mobile phone and game console for diabetes management	Patients were connected to their care provider who had access to their electronic records. They were also asked to upload glucose readings wirelessly through glucometers connected to mobile phones. Patients were also given email access to the care providers and an access to the educational programmes in the web through a game system	Majority of the patients liked the wireless system for glucose monitoring and receiving automatic feedback. However, patients expressed frustration over using cell phone and the game system every day	Lyles et al. (21)

**Table 1** Continued

Sl.	Title of the article	Types of study/duration	Sample size/type of diabetes/mean age (years)	Technology used	Aim of the study	Methodology	Outcome	References
4	A randomised controlled trial of a nurse short-message service by cellular phone for people with diabetes	Randomised control trials/ 12 weeks	60 Type 2 diabetes mellitus/ 47.5 for Control group, 46.8 for Intervention group	Website and SMS	To assess the effect of sending optimal recommendations by SMS on plasma glucose levels	Patients in the intervention group were asked to access a website by using a cellular phone or to wired Internet and input their blood glucose levels every day. Participants were sent the optimal recommendations by both cellular phone and the Internet weekly	Intervention group had a significant mean decrease in HbA1c and 2 h PPG	Kim (26)
5	A nurse short message service by cellular phone in type-2 diabetic patients for 6 months	Randomised control trials/ 6 months	60 Type 2 diabetes mellitus/ 47.5 for Control group, 46.8 for Intervention group	Website and SMS	To investigate the effect of sending individual recommendations by SMS on glycaemic control	Participants in the intervention group were requested to input their blood glucose level, diet and exercise diary every day in the website by cellular phone or wire Internet. The researcher sent optimal recommendations to each patient using SMS by cellular phone and wire Internet weekly	HbA1c and 2 h PPG were decreased significantly in the intervention group during the study	Kim and Jeong (27)
6	Effectiveness of mobile and Internet intervention in patients with obese type 2 diabetes	Randomised control trials/ 12 months	40 Obese type2 diabetes mellitus/ 48.5 for Control group, 45.5 for Intervention group	Website and SMS	To investigate whether using a web-based diary would improve glycaemic control	Patients in the intervention group were requested to record their blood glucose level in a weekly diary on the website by personal cellular phones or computer Internet. The researcher sent optimal recommendations to each patient, by both the cellular phone and the Internet weekly. Control group received the usual care	There was a progressive improvement in the HbA1c levels over 1 year. There was also a significant decrease in 2 h postprandial glucose levels	Kim and Kim (28)

**Table 1** Continued

Sl.	Title of the article	Types of study/duration	Sample size/type of diabetes/mean age (years)	Technology used	Aim of the study	Methodology	Outcome	References
7	Impact of web-based nurse's education on glycosylated haemoglobin in type 2 diabetic patients	Randomised control trials/ 12 weeks	60 Type 2 diabetes mellitus/ HbA1c < 7: 49.2 for Control group, 50 for Intervention group HbA1c > 7: 46.2 for Control group, 43.4 for Intervention group	Website and SMS	To evaluate whether effect of nurse's education through SMS varied with respect to the baseline HbA1c	Patients in the intervention group received patient education using SMS by a nurse. Short message service intervention was performed weekly for 12 weeks. Participants were requested to update the blood glucose level, diet and exercise diary every day in the web portal by cellular phone or Internet. The nurse sent optimal recommendations to each patient using SMS of cellular phone and wire Internet	Patients with baseline HbA1c $\geq$ 7% showed a significant reduction in the HbA1c in the intervention group whereas, patients with baseline HbA1c < 7% were able to maintain their control in the intervention group	Hee-Sung (25)
8	Telemedicine and type 1 diabetes: is technology <i>per se</i> sufficient to improve glycaemic control?	Randomised control trials/ 6 months	180 Type1 diabetes mellitus/ 25 for Control group (Low users), 33 for Intervention group (high users)	Smartphone application called Diabeo app, Insulin dose Advisor (IDA)	To investigate the use of Diabeo App for insulin dose adjustment to improve HbA1c	Patients were divided into three groups. Standard quarterly follow-up group, smart phone with Diabeo app with quarterly visits group and smart phone with Diabeo app and fortnightly teleconsultation group	HbA1c improved significantly among the users of the Diabeo app either with or without teleconsultation. However, there was a greater improvement in HbA1c among those who had teleconsultation	Franc et al. (13)
9	Stepwise self-titration of oral glucose-lowering medication using a mobile telephone-based telehealth platform in type 2 diabetes: a feasibility trial in primary care	Randomised control trials/ 6 months	14 Type2 diabetes mellitus/ 60 for Control group, 56 for Intervention group	Web-based tools	To investigate the use of telehealth system to adjust the doses of oral hypoglycaemic agents for improving glycaemic control	Type 2 diabetes patients were randomised to control and intervention groups. Intervention group was instructed to follow a stepwise treatment plan using real-time graphical feedback on a mobile telephone and remote nurse monitoring using a web-based tool	There was a greater decrease in HbA1c in the intervention group when compared with the control group	Nagrebetsky et al. (16)

**Table 1** Continued

Sl.	Title of the article	Types of study/duration	Sample size/ type of diabetes/mean age (years)	Technology used	Aim of the study	Methodology	Outcome	References
10	Mobile phone-based remote patient monitoring system for management of hypertension in diabetic patients	Pilot Study/ 4 months	33 Type2 diabetes mellitus/ 58.1	SMS, Smartphone application for BP monitoring	To assess the effectiveness of the home BP telemanagement system in improving BP control	Patients with uncontrolled ambulatory BP were provided with BP monitoring device connected to a mobile phone. Patients were asked to take two consecutive reading in mornings and evenings for minimum of 2 days per week. Critical alerts were sent automatically by fax to the physician if the average of 12 consecutive readings measured over a 3-day period exceeded the preset threshold values	BP control was found to be improved significantly. Patients reported the system as acceptable and effective	Logan et al. (18)
11	Teleophthalmology assessment of diabetic retinopathy Fundus images: Smartphone vs. standard office computer workstation	Retrospective, comparative study	55/51	Web-based image archiving and forwarding programme (i2iTele-Solutions)	To evaluate the use of Smartphone vs. Computer for assessing fundus images from diabetic retinopathy patients	Patient's images acquired using non-mydiatic cameras were transmitted with medical data 20 miles away through computer workstation (gold standard) and through iPhone. Two ophthalmologists independently compared images	Ophthalmic images transmitted through both smart phone and Internet techniques matched well with each other. Image quality of iPhone was scored high by the ophthalmologists	Kumar et al. (23)

**Table 2** Mobile applications for patient behaviour modification

Sl.	Title of the article	Types of study/ duration	Sample size/ type of diabetes/mean age (years)	Technology used	Aim of the study	Methodology	Outcome	References
1	Contracting and monitoring relationships for adolescents with type 1 diabetes: a pilot study	Pilot Study/ 3 months	10 Type 2 diabetes mellitus/ 14–18 years	Telephone, SMS, e-mail	To assess effect of combination of a behavioural contract and a cell phone glucose monitoring system on the glycaemic profile and behavioural pattern of adolescent patients	Adolescents with type 1 diabetes aged between 14 and 18 years living with at least one parent participated. Semi-structured personal interviews were used to gather information from each parent–adolescent pairing. Based on that a behavioural contract was made with each parent–patient pair. A cell phone-glucose meter was given to patients to monitor the contract. Telephone or text-message (SMS) contacts were made directly with the patient. Parents were asked to reduce the frequency of questioning their child about his or her self-monitoring behaviour	A significant reduction in HbA1c and a significant improvement in the diabetes self-management profile was reported	Carroll et al. (20)
2	Evaluating self-management behaviours of diabetic patients in a telehealthcare programme: longitudinal study over 18 months	Pilot Study/ 18 months	162 Type 1 and Type 2 diabetes mellitus/ 52.55 for control and 51.3 for intervention	Website, SMS	To investigate the behavioural pattern of diabetic patients using telehealthcare programme and its effect on glycaemic control	Patients in the intervention group were provided with mobile telecommunication glucometer, an online diabetes self-management system, and a teleconsultant service. Patients and caregivers could communicate through the online diabetes self-management system using internal message service or SMS messaging. Teleconsultant service supported the patients with diabetes self-management	Five behaviours namely being active, healthy eating, taking medication, healthy coping and problem solving were found to be significantly improved at the end of the study. HbA1c levels were decreased significantly and also there was an increase in glucose monitoring	Chen et al. (30)



**Table 2** Continued

SI.	Title of the article	Types of study/ duration	Sample size/ type of diabetes/mean age (years)	Technology used	Aim of the study	Methodology	Outcome	References
3	Using mobile phones to measure adolescent diabetes adherence	Feasibility study/ 10 days	96 Type 1 diabetes mellitus/ 14.96	Cell phone	To determine the feasibility of using cell phone-based ecological momentary assessment to measure patient adherence behaviour	Ecological momentary assessment was done to survey the behaviours and experiences of patients in real time using mobile devices. An automated interactive touch tone telephone response system using a commercially available interactive voice response system that uses recorded questions was used. Participants were called twice per day for 10 days. Calls were always initiated on a weekday and continued for 10 days to include at least one weekend	It provided a feasible method to measure patient adherence to glucose monitoring and insulin administration. However, the adherence was not correlated with glycaemic control	Mulvaney et al. (24)
4	Evaluating the impact of mobile telephone technology on type 2 diabetic patients' self-management: the NICHE pilot study	Randomised control trials/ 3 months	30 Type 2 diabetes mellitus/ 56.7 for control and 55.3 for intervention	SMS	To examine the use of interactive cell phone technology in improving the diabetes self-care and clinical outcomes	Patients were randomised to NICHE (Novel Interactive Cell-phone technology for Health Enhancement) or standard diabetic care. Patients under NICHE group were required to test their glucose once daily, wear pedometer and upload data onto the NICHE server once daily. They received tailored messages via mobile phone based on the uploaded data. Both patient and provider were able to view readings from uploaded data	There was an improvement in HbA1c but not significantly. Self-efficacy scores were significantly improved in the intervention group. The system was not user friendly	Faridi et al. (19)
5	The development and feasibility of a web-based intervention with diaries and situational feedback via Smartphone to support self-management in patients with diabetes type 2	Pilot study/ 3 months	15 Type 2 diabetes mellitus/ 59.6 years	Website and SMS	To test the feasibility of using Smartphone enabled web-based diary in self-management of diabetes	The intervention included use of a smart phone enabled access to web-based daily diaries and individualised written situational feedback. The participants were asked to register their eating behaviour, medication, physical activities and emotions three times daily using the mobile device. They also registered their	Patients reported that the intervention was supportive and meaningful. Most of the participants reported positive lifestyle changes	Nes et al. (31)

**Table 3** Mobile applications for patient education

Sl.	Title of the article	Types of study/ Duration	Sample size/ type of diabetes/mean age (years)	Technology used	Aim of the study	Methodology	Outcome	References
1	Diabetes self-management Smartphone application for adults with type 1 diabetes: randomised controlled trial	Randomised control trials/ 9 months	72 Type1 diabetes mellitus/ 34.4 for control and 35.97 for intervention	Smartphone application called Glucose Buddy, SMS	To examine effectiveness of Smartphone application combined with SMS feedback from diabetes educator on glycaemic control, quality of life and self-care	Patients were randomised to smart phone application group and control group (usual care). Patients in the intervention group received weekly text message for 6 months and all the patients were followed up for 3 months after the treatment period. Outcome measures were collected every 3 months during the study	The smart phone application intervention showed a significant improvement in HbA1c, but there was no significant change in quality of life and self-care activities	Kirwan et al. (32)
2	Feasibility of a mobile phone-based data service for functional insulin treatment of type 1 diabetes mellitus patients	Pilot study/ 3 months	10 Type1 diabetes mellitus/ 36.6	Smartphone application called Diab-Memory, Web site, and SMS	To evaluate the feasibility and user acceptance of a mobile phone app-based support to assist diabetic patients	A software application called Diab-Memory was developed to provide a mobile phone-based diabetes diary to collect and to transmit daily key measurements to a remote monitoring centre. Patients were provided with secured access to update insulin doses, content of carbohydrates in meals, physical activities and symptoms of hypoglycaemia. The data were analysed to generate statistics and trends and were provided to the patients and care providers	The system was well accepted by patients. There was a significant decrease in HbA1c	Kollmann et al. (33)
3	A ubiquitous chronic disease care system using cellular phones and the Internet	Randomised control trials/ 3 months	123 Type 2 diabetes mellitus/ 59.4 for control and 57 for intervention	Ubiquitous Chronic disease care (UCDC) system, SMS	To investigate the effectiveness and applicability of Smartphone-based Ubiquitous Chronic Disease Care (UCDC) system for diabetes care	Patients in the intervention group were given access to UCDC system via Smartphone. It sent alarm over cell phone to remind to measure blood glucose, pressure twice day, weight once day and transmitted the results to central database. After sending the data, patients immediately received messages. They received three messages daily regarding diet and exercise methods. Patients in the control group received the usual care	There was a significant reduction in the HbA1c levels. Blood pressure, total cholesterol, LDL and triglyceride levels were also significantly decreased	Yoo et al. (29)

**Table 3** Continued

Sl.	Title of the article	Types of study/ Duration	Sample size/ type of diabetes/mean age (years)	Technology used	Aim of the study	Methodology	Outcome	References
4	Cluster-randomised trial of a mobile phone personalised behavioural intervention for blood glucose control	Randomised control trials/ 12 months	163 Type 2 diabetes mellitus/ 53.2, 52.8, 53.7 and 52 years for control, intervention groups 1, 2, and 3 respectively	Website and SMS	To test whether adding mobile application coaching would reduce HbA1c in patients with type 2 diabetes	A patient coaching system based on mobile application and web portal was used as intervention. Intervention group was divided into three subgroups. Patients in all the intervention groups received the coaching system. First group received coaching only. In second group, care providers were given patient data access. In third group, the care providers were given data access with decision support	Substantial reduction in HbA1c was observed in the maximal treatment group. There was no difference in patient-reported diabetes symptoms, diabetes distress, depression, BP and lipid profiles between the groups	Quinn et al. (22)
5	Patients' engagement with 'Sweet Talk' – a text messaging support system for young people with diabetes	Randomised control trials/ 12 months	64 Type 1 diabetes mellitus/ 8–18 years	SMS, Smartphone App called Sweet Talk system	To explore how T1DM patients interact with the Sweet Talk system to understand its utility	Patients participated in a trial which used sweet talk in the intervention arm were included for this study. All text messages submitted to Sweet Talk during study period were recorded. Messaging patterns and content were analysed using mixed quantitative and qualitative methods	Automated, scheduled text messaging successfully engaged young people with diabetes. Patients clinical and sociodemographical characteristics were not associated with total messaging frequency	Franklin et al. (14)

management (Table 1), five articles related to mobile applications for patient behaviour modification (Table 2) and five articles related to mobile applications for patient education (Table 3). Among 11 studies on mobile applications for diabetes management two articles were related to mobile-based diary applications, five were related to web-based diary applications, three were related to telemonitoring applications and one mobile application was related to remote diagnosis for evaluation of ophthalmic images. Of five studies on mobile applications for patient behaviour modification, two were related to applications for patient behaviour monitoring, while one was related to applications for patient adherence monitoring, and two were related to applications for supporting patient self-care. Remaining five articles were related to mobile applications for patient education.

### Mobile applications for diabetes management

This systematic review extracted 11 original scientific papers focusing on managing diabetic patients using mobile applications. Those studies were either randomised controlled trials or clinical cohort-based studies having study duration between 12 weeks and 1 year with good number of type 1 or type 2 diabetic patients and a wide age range between 18 and 75. The technologies used were smartphone apps- or web-based diary, one study used iPhone in reviewing images for funduscopy examination. These articles were further subdivided according to the type of application used for diabetes management such as mobile-based diary applications, web-based diary applications, telemonitoring applications and remote diagnosis.

### Mobile-based diary applications

Diabetes clinics usually provide a paper-based diary followed by home monitoring through phone calls to support the self-management of patients. However, with the recent advancements in mobile phone technology, a mobile phone diabetes digital diary that can be accessed by the healthcare team via web has become possible. Many clinical studies have evaluated the utilisation of these mobile-based diaries. Use of mobile phone-based diabetes diary for self-titration of insulin dose resulted in the significant decrease in HbA1c in patients with type 2 diabetes (15). However, when a similar mobile-based diabetes diary was used in patients with type 1 diabetes, it could not achieve a statistically significant reduction in HbA1c and other glycaemic parameters such as fasting blood glucose and postprandial glucose (PPG) (17). This could be attributed to the relatively lower baseline HbA1c levels (9.5% vs. 7.6%) in the type 1 diabetic patients. On the other hand, there

was a significant decrease in the fluctuations in the glycaemic parameters, indicating the impact of the intervention.

### Web-based diary applications

Effect of web-based patient monitoring and intervention in diabetes management was explored in different studies. In one study, patients were required to enter daily blood glucose readings online through mobile phones and received automatic feedback. They were also given access to educational programmes on the web through a video game console. While the intervention improved the patient self-care, many patients expressed frustration over using mobile phone and game console multiple times every day (21).

A web-based diary was used in one study for the management of type 2 diabetic patients. Access to online web diary was given to each patient and they received optimal recommendations through email or mobile phone after uploading their daily blood glucose readings. This resulted in a significant improvement of HbA1c and PPG in patients after 12 weeks (26), 6 months (27) and 1 year (28). Hee-Sung (25) evaluated a web-based patient monitoring and nurse's education through SMS in type 2 diabetic patients. HbA1c levels were found to be significantly decreased in patients with uncontrolled glycaemia (HbA1c > 7%) and patients with good control (HbA1c < 7%) at the start of the study were able to maintain their control. These results show that patient-monitoring through web-based tools and mobile phones are effective in improving the glycaemic parameters up to 1 year and are useful in maintaining a good control of glycaemia. However, necessity of frequent use of smartphone and websites for patient monitoring may lead to a decreased compliance among patients.

### Telemonitoring applications

Telemonitoring of patients with smartphone applications and mobile technology is the most common approach of the mobile health platforms. When a smartphone App (Diabeo) for insulin dose adjustment with or without teleconsultation was evaluated in type 1 diabetic patients, there was a greater improvement of HbA1c among the patients who used the Diabeo App with teleconsultation (13). Nagrebetsky et al. (16) investigated telehealth system with real-time graphical feedback and remote nurse monitoring through mobile phones for adjusting the dose of oral hypoglycaemic agents in type 2 diabetic patients. The study concluded with a significant decrease in the HbA1c levels. In another study, remote patient monitoring using home BP

telemanagement system was investigated in type 2 diabetic patients with uncontrolled ambulatory hypertension. The remote BP monitoring decreased the 24 h ambulatory BP and the BP control was significantly improved (18). Patient telemonitoring using mobile phones provide a close support to the patients. It seems that access to the healthcare team and timely feedback facilitated the treatment optimisation and increased patient compliance to achieve a better control of diabetes.

### Remote diagnosis applications

Mobile technology can also be used to transmit data for conducting remote diagnosis. This technique can provide more time for the care providers to review the data and make informed decisions. Kumar et al. (23) used an iPhone-based specific image archiving and forwarding programme (i2i telesolutions) to view and report the diagnosis on diabetic retinopathy fundus images in the mobile phones. The study concluded that diagnosis using mobile phones matched well with that of images stored in computer and the quality of images viewed on the iPhones were reported high by the ophthalmologists.

### Mobile applications for patient behaviour modifications

Among the final list of articles, five were found to have investigated diabetic patient behaviour modifications using mobile applications. Most of the studies were randomised controlled trials or clinical cohort-based studies with study duration between 10 days and 18 months, recruited type 1 or type 2 diabetic patients with age ranging between 14 and 60. The mobile health technology used was smartphone apps with diary or telephone- or web-based applications.

Standard diabetes management regimens include patient behaviour modification strategies to achieve better glycaemic control. However, these often fail to bring the desired lifestyle changes due to the lack of efficient patient monitoring systems. Wide availability of smartphones has brought the patient remote monitoring close to reality. Articles that report use of mobile applications for patient behaviour modifications were further classified as applications for patient behaviour monitoring, applications for patient adherence monitoring and applications for supporting patient self-care.

### Applications for patient behaviour monitoring

Many researchers have investigated the implementation of mobile applications for diabetes behavioural monitoring. Carroll et al. (20) used the cell phone-connected glucometer with telephone and SMS

communication to monitor the behavioural pattern in adolescent type 1 diabetic patients. The study reported a significant improvement in the self-management profile and a reduction in HbA1c. In another study, a telehealthcare programme was used to monitor self-management behaviour in adult type 2 diabetic patients (30). In addition to the cell phone-connected glucometer, they used an online diabetes self-management system with teleconsultant service. This resulted in improvement of healthy behaviours, increased glucose monitoring and a significant reduction in HbA1c. Results from these studies show that behavioural monitoring of the patients with the cell phone-based applications is useful in inducing lifestyle modifications to achieve glycaemic control.

### Applications for patient adherence monitoring

The requirement of multiple medications and the demand for lifestyle changes pose a huge challenge for patient adherence. Many diabetic clinics have programmes for closely following the patients to ensure patient adherence. Arrival of mobile health technology has provided an ideal platform for such patient follow-up programmes. A cell phone-based ecological momentary assessment tool was used to measure the patient adherence behaviour (24). The method was found to be feasible in measuring the patient adherence to glucose monitoring and insulin administration. The adherence assessed through the intervention was comparable to the traditional self-report data but did not correlate with the glycaemic control due to the shorter study duration (10 days).

### Applications for supporting patient self-care

Self-care and self-efficacy are very important patient characteristics that have a strong influence on the diabetes management. Mobile health interventions can be used to build patient support systems to enhance self-care and self-efficacy behaviours. Faridi et al. (19) used interactive cell phone technology to improve the diabetes self-care. Patients were required to upload the data every day for care provider's review and would receive recommendation messages. Although patients reported the system was not user friendly, the self-efficacy scores were significantly improved. However, there was only a negligible decrease in HbA1c levels. This was attributed to the low patient adherence arising out of the lack of user-friendly system. A web-based daily diary with individualised situational feedback was used by Nes et al. (31) to support the diabetes self-management. Patients recorded their daily self-care activities in the diary using their mobile phones and received feedback messages. This intervention was found to be

supportive and meaningful. Most of the study patients reported positive lifestyle changes. These outcomes indicate that remote monitoring of the patient activities with care provider feedback were found to be supportive in improving patient self-care. Nevertheless, these mobile-based systems need to be user-friendly for the patients to use them comfortably and comply with the treatment requirements.

### Mobile applications for patient education

This systematic review extracted five original scientific papers focusing on diabetic patient health education using mobile applications. Those studies were either randomised controlled trials or clinical cohort-based studies having study duration between 12 weeks and 1 year with good number of type 1 or type 2 diabetic patients and a wide age range between 8 and 60. The technology used was smartphone apps with diary.

Patient education is crucial in improving the adherence behaviour and inducing lifestyle modifications. Inadequate knowledge about the disease and its management may hinder the self-care activity among patients leading to even treatment failures. Thus, patient education has been an essential part of diabetes treatment plans.

Smartphone applications can be used to ensure active participation of patients to mobile health interventions. These apps are generally used for collecting patient data to personalise the educational content. Kirwan et al. (32) used 'Glucose Buddy' a freely available iPhone diabetes management application in type 1 diabetic patients to collect patient information and send SMS feedback. Although, there was a significant improvement in HbA1c, the quality of life and self-care activities did not improve. The change in self-care activities and quality of life do not always correlate with HbA1c in type 1 diabetic patients (19,34).

The feasibility and user acceptability of a smartphone-based diabetes diary 'Diab-Memory' in type 1 diabetic patients was explored by Kollmann et al. (33). The application was used to collect and transmit patient data to a remote monitoring centre. Patients were sent reminder messages and were given analysed data output with statistics and trends. The application was well accepted by the patients and it decreased the HbA1c significantly. Another smartphone application called 'Ubiquitous Chronic Disease Care' (UCDC) system for diabetes care was investigated in type 2 diabetic patients (29). The application sent alarms to remind patients about daily self-care activities. Patients were also able to send their data and received educational messages. The UCDC intervention had a significant impact on

the clinical parameters such as HbA1c, BP and lipid profile. These smartphone apps required the patients to upload their daily data and sent reminders about their self-care activities. Although the feedback messages were mostly educational and motivational, the glycaemic and other clinical parameters were greatly improved. While the educational messages and reminders support the patient self-care, the smartphone application keeps the patients involved and thereby increasing the patient adherence.

Quinn et al. (22) assessed the use of a patient-coaching system based on a mobile diabetes management software application and a web portal. Patients entered self-care data to the mobile application and received automated, real-time, educational, behavioural and motivational messages appropriate to their data. Care providers were given data access only or data access with decision support. While the patient reported diabetes symptoms, diabetes distress, depression, BP and lipid profiles did not differ between the groups, there was a significant reduction in HbA1c in the group in which physicians were given decision support. It is obvious that when the care providers are given decision support, they will be proactive and take timely decisions. Patient response to messages sent through a patient support application 'Sweet Talk' was investigated in patients with type 1 diabetes (14). Automated and scheduled text messaging was able to engage the young diabetic patients, but patient responses were not influenced by the socio-demographical characteristics.

Results from various studies discussed above indicate that educational text message interventions using smartphone apps could increase the patient involvement and thereby enabling them to achieve glycaemic and metabolic goals. Even as the unidirectional educational messages are economical and easier to implement, the lack of active patient engagement might adversely affect the outcomes.

This review has shown that mobile health interventions, when used for diabetes management or patient education or patient behaviour monitoring resulted in significant clinical improvement. Most of the studies (76%) reported positive outcome after the use of the mobile health applications. Although interventions with smartphone apps were able to produce significant results, providing continuous patient support using mobile phones may be a challenging task and would require adequate infrastructure and personnel. Cost benefit and cost-effectiveness analysis with these mobile interventions may be necessary for care providers to decide on implementation of such systems.

Strength of this study is that we included all peer-reviewed articles with original clinical studies related



to smartphone apps. Limitations of this review include using only PubMed database for the literature search. We could have missed some important papers that were published in other databases. Although some studies used mobile phone-connected devices for data collection, many of the studies reported patient entered data without any validation. Outcomes of such studies need to be reviewed with caution. Wide age range of patients might have influenced the study outcomes since the utilisation of smartphones could have varied with the patient's age. Varied objectives, study methodologies, duration and patient characteristics prevented us from doing a meta-analysis. Another limitation is the small number of papers currently available in the literature for certain mobile applications. Results of our review should be interpreted with keeping all these limitations in mind.

## Conclusion

The smartphone and web applications offer significant benefits for patient care, education and behavioural modifications. Web-based tools have shown very good effect on diabetic patient management and education but had limited behavioural

modification role. Smartphone apps have been only tested for either patient management or education with variable response. They were found to be the best for education and telemonitoring. Phone calls are becoming less popular and we found only two studies that have been used for behavioural modification with good outcome. Smartphone apps and teleconsultation techniques fared better in the clinical outcomes. Long-term cost benefit and cost-effectiveness analysis studies with the mobile health interventions are essential before implementing them in the routine practice.

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## Author contributions

SKD and MRM developed the concept, performed publication search and analysis, and prepared the manuscript.

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