Review Article

The evidence for using mHealth technologies for diabetes management in low- and middle-income countries

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Abstract: Worldwide, diabetes is a significant cause of death and disability, accounting for approximately 29 million years of life lost (YLLs) in 2016. Low- and middle-income countries (LMICs) are particularly challenged by diabetes, with fewer patients achieving control of their condition, younger average age of onset, escalating prevalence rates, coupled with healthcare system shortages. Mobile health (mHealth) technologies have been proposed as cost-effective, widely accessible strategies for overcoming many of the barriers to effective diabetes management. mHealth interventions enable the real-time exchange of information between patients and healthcare providers, allowing for responsive and timely treatment recommendations, which has the potential to increase the capacity of patients in self-managing their conditions. Previous reviews of mHealth interventions for diabetes care have found positive effects on key diabetes outcomes. However, to date, all reviews have largely reported on studies conducted in high-income countries (HICs). The effectiveness of these interventions in LMICs is less clear. This review provides an assessment of the published evidence for the effectiveness of mHealth interventions on key diabetes outcomes in LMICs. The electronic databases PubMed, Ovid Medline, CINAHL and SCOPUS were comprehensively searched to identify eligible studies. Only randomized controlled trials (RCTs), controlled trials, randomized head-to-head trials and systematic reviews with meta-analyses were eligible for inclusion. The database search yielded 1,019 unique records. Nine studies were included in the final review. Six studies reported significant, positive effects of the intervention on at least one key diabetes outcome measure. Whilst few studies evaluated the intervention on behavioural outcomes, there was an indication that mHealth interventions can elicit positive change on key diabetes self-care behaviours such as medication adherence. The review found promising but limited evidence for the effectiveness of mHealth interventions for improving glycaemic control in LMICs. It is timely that researchers examine the effectiveness of various mHealth interventions for diabetes care using rigorous study designs, scalable interventions, measuring both clinical and behavioural diabetes-related outcomes in LMICs.

Keywords: Diabetes mellitus; telemedicine; review; developing countries

Received: 15 June 2018; Accepted: 02 July 2018; Published: 20 July 2018.
doi: 10.21037/jhmhp.2018.07.01
View this article at: http://dx.doi.org/10.21037/jhmhp.2018.07.01

Introduction

Both high-income countries (HICs) and low- and middle-income countries (LMICs) are grappling with the challenges of effectively managing escalating diabetes epidemics (1,2). Annually, 4.6 million deaths worldwide are directly attributable to diabetes, 80% of which occur in LMICs (3-6). Most people with diabetes worldwide do not meet International Diabetes Federation (IDF) treatment targets of glycaemic control, i.e., glycosylated haemoglobin (HbA1c) ≤7% (2,7-10). The proportion of people with

diabetes achieving this target is lowest in LMICs (1,11,12). LMICs report younger average age of diabetes onset, higher rates of diabetic complications and mortality and sharper increases in prevalence rates than HICs (3,4,6).

In many LMICs, diabetes care is compromised by many patient-related, societal and health system factors (1). Patient-related factors include poor knowledge of the disease and its treatment (1,4). Societal and health system factors include diabetes workforce shortages, lack of standardized care protocols, inadequate infrastructure and unaffordability due to poverty and limited public funding (1,4,11,13). There is an urgent need for cost-effective and widely accessible strategies for empowering and motivating people with diabetes to adhere to best-practice diabetes self-care behaviours (12,14-17). The expanding information and communication technologies (ICT) industry has received considerable interest for its potential to assist with the worldwide failure to control diabetes (18,19).

Mobile health (mHealth), has been defined as the use of mobile communication devices to transmit information with the objective of advancing health (19,20). In low-income countries (LICs), mobile communication technology is the most rapidly growing sector of the ICT industry, and geographical coverage even in these economies is high (21). As of 2015, an estimated 80% of the world's population possessed a mobile device (20). These technologies have been proposed as cost-effective tools to supplement clinician visits and means to deliver continuity of care, which could overcome the clinician shortages particularly evident in LMICs (5,14,19,22).

mHealth technologies possess a variety of attributes that may enable them to deliver benefits to healthcare consumers and healthcare providers (18,20). mHealth tools can facilitate real-time communication between healthcare providers and patients (18,20). They can provide timely, convenient, high-quality and personalized support (14,18,19,23). The bi-directional exchange of information enabled by mobile devices means patients can be effectively monitored from a distance (20).

There have been numerous systematic reviews of mHealth applications for diabetes management, many of which have reported positive intervention effects (14,21,24-27). However, others have been less conclusive (9,28,29). While there is growing evidence that various mHealth devices and applications have the potential to improve clinical and/or behavioural diabetes-related outcomes, all these reviews exclusively or predominantly included studies conducted in HICs. Consequently, the evidence to support the use of mHealth interventions for diabetes care in LMICs is less clear (22).

Critical differences in mobile phone usage between HICs and LMICs preclude the extrapolation of findings from HICs to LMICs (18,30). Furthermore, mHealth interventions have the potential to be widespread and offer great benefit in these regions if found to be effective (18,31). There have been numerous recently reported trials of mHealth interventions for diabetes management in LMICs. However, a formal review of this nascent, yet rapidly flourishing field is yet to be conducted. To address this research gap, the present review synthesizes the evidence in this field to the present time, identifies gaps in the research, and offers directions for future research.

Methods

Search strategy

Electronic searches of PubMed, Ovid Medline, CINAHL and SCOPUS databases were conducted, seeking eligible studies published in English in a peer-reviewed journal between September 2000 and December 2017 (inclusive) and available in full text. The search strategy comprised three categories of terms: 'diabetes', 'mobile health technology' and 'low- and middle-income countries' and synonyms of each.

Study selection process

One reviewer screened the titles and abstracts of all search results based on the inclusion and exclusion criteria. The full texts of all potentially eligible studies were retrieved. The same reviewer screened all full texts and assessed each study for its eligibility. In cases of uncertainty, a second reviewer assessed the study for eligibility.

Inclusion criteria

To be included in this review, studies must have trialled interventions using mobile devices with the capacity for mobile and/or wireless communication and/or devices with software applications. Included studies must have trialled interventions that incorporated a two-way flow of information. That is, interventions must have been interactive insofar as the information/recommendations communicated to the user was personalized and dependent on the information provided by that person. To be

included, studies must have trialled an intervention where the mHealth component was the key feature of the intervention. To be included, interventions could have been directed at any level of care, i.e. targeted directly at patients or at healthcare providers to improve the advice or care given to patients. Additionally, interventions must have been designed to improve key diabetes outcomes, either self-care behaviours (e.g., medication adherence) or clinical measures (e.g., HbA1c). Studies must have evaluated the intervention on: at least one diabetes-related clinical outcome measure; at least one diabete self-care behaviour; or, hospital admissions, or mortality.

Included studies must have described a randomized controlled trial (RCT), a controlled trial with non-random allocation, a randomized head-to-head trial, or a systematic review with meta-analysis that included only primary studies of these designs. These study designs were considered the most rigorous for assessing intervention effects.

Inclusion criteria for participants were: studies conducted in any LMIC according to World Bank classification data as of 2018; and participants who were patients must have had diabetes mellitus of any type. The year 2018 was chosen as countries tend to move up rather than down in income classification and is therefore the most restrictive criterion for income level (32).

Assessing risk of bias in included studies

The Cochrane Collaboration's tool for assessing risk of bias (33) was utilized for included studies. The primary reviewer assessed each study on each criterion of this tool and consulted a second reviewer in cases of uncertainty. This tool consists of two criteria for assessing selection bias and one criterion each for assessing performance/detection bias, attrition bias, reporting bias and other sources of bias.

Results

The search strategy identified 1,019 results. After removing duplicate records, there were 679 unique records. Of these, 559 were excluded after reviewing the title and abstract. Of the remaining 120 records, three of the full texts were not retrieved within the timeframe despite numerous attempts and were thus excluded. Based on a full text review of the remaining 117 records, 105 results were excluded, as they did not satisfy all the inclusion criteria. Twelve results met the inclusion criteria but three were duplicate publications of a single study. Two such publications were excluded from the present review, as both have subsequently been retracted by the respective publishers. The third was excluded because it was a summary of the other articles and lacked sufficient detail to determine eligibility. Thus, nine studies were included in the final analysis. *Figure 1* represents the results of the database search and study selection process.

Characteristics of included studies

The characteristics of included studies are depicted in *Table 1*.

All studies were published between 2012 and 2017. Five studies were conducted in upper-middle-income countries (34,36,38,40,41), three in lower-middle-income countries (37,39,42) and one in a low-income country (35). Sample size ranged from 37 to 440, with a median of 100. All studies described interventions at the patient level, where information exchange took place between patients and healthcare providers. One study also incorporated a smartphone application (app) for providers that assisted the decision-making process (42). Seven out of the nine studies trialled some variation of an online portal where patients submitted diabetes-related clinical and self-care data and receive personalized recommendations based on health status (34-36,38,40-42). The other two studies trialled telephone consultations between patients and healthcare providers (37,39). Eight studies were conducted either exclusively or predominantly among people with type 2 diabetes, whilst one study (34) included people with predominantly type 1 diabetes.

The primary outcome for all studies was glycaemic control measured by at least one clinical indicator, such as HbA1c. Other clinical outcomes included fasting blood sugar, high-density lipoprotein (HDL), low-density lipoprotein (LDL), total cholesterol, triglycerides, fructosamine, postprandial blood sugar (PPBS), fasting plasma glucose, blood pressure, weight, hip and waist circumference and body mass index (BMI). Self-reported outcomes included adherence to medication, rates of blood glucose testing, and diabetes self-care behaviours (measured using standardized instruments). Four studies did not report between-group analyses on several or all described outcome measures (35-37,39,42).

Intervention effects

Intervention effects by outcome measures

Refer to *Table 2* for all between-group analyses by outcome measures. Six studies (34,36,37,40-42) compared average

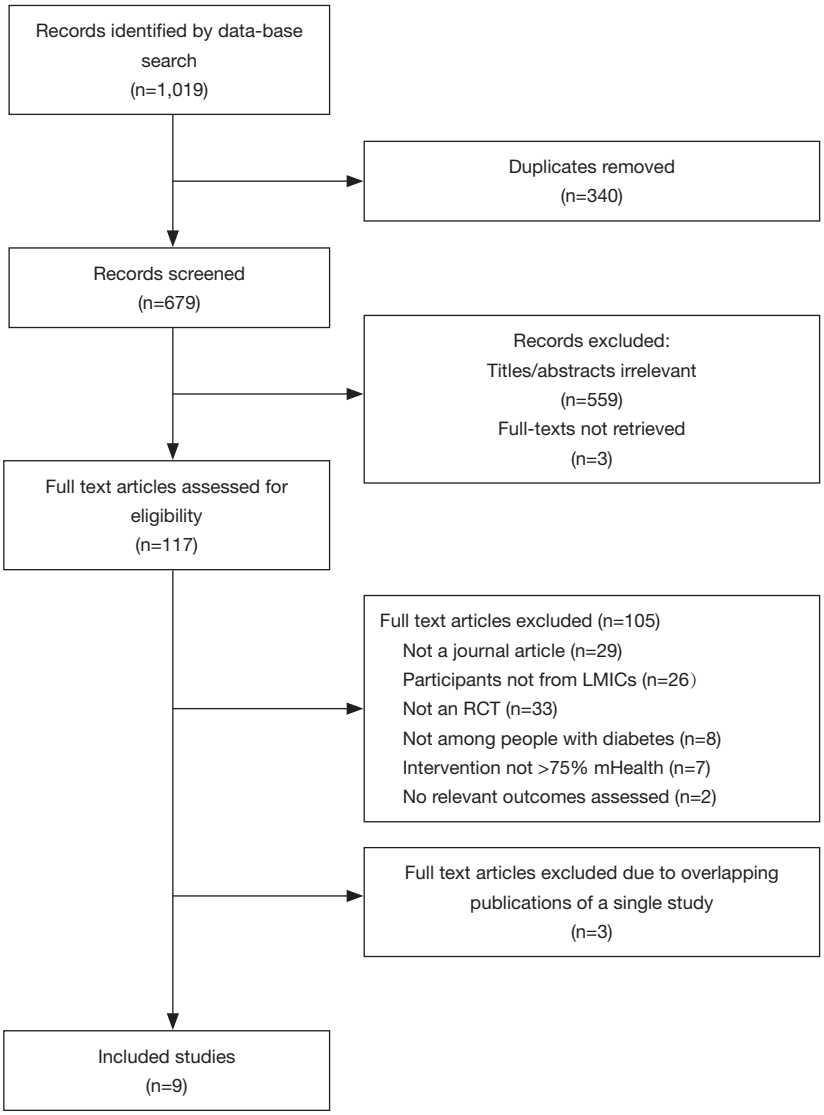

Figure 1 Represents the results of the database search and study selection process.

change in HbA1c between conditions, of which four reported greater average reduction in HbA1c levels for the intervention condition. Two studies reported P<0.001 (34,41), one reported P<0.01 (36) and one reported P=0.02 (42), while two studies (37,40) reported a non-significant difference between conditions.

Two studies compared the proportion of participants achieving target HbA1c levels between conditions (36,39). Zhou *et al.* (36) reported that 66.04% of the intervention group, compared to 42.27% of the control group achieved target HbA1c levels (i.e., HbA1c <7.0%) post-intervention, a difference they reported to be statistically significant, however the p-value was not reported. The other study by Shahid *et al.* (39) did not report the proportion in each group that achieved normal HbA1c levels, however reported the adjusted risk ratio =2.71 (P=0.023).

Out of the five studies that analysed change in fasting blood sugar, two studies reported significant intervention effects (36,41). In these two studies, the intervention groups reported average reductions of 30.1 and 34.2 mg/dL, compared to the average reduction among the control groups—12.8 and 17.3 mg/dL, respectively (36,41). The study by Zhou *et al.* (41) reported P<0.01, and the study by Zhou *et al.* (36) reported P<0.05.

Table 1 Characteristics of included studies

Author, year (ref)	Country	Study design	Sample size (baseline/ follow-up)	Age range (years)	Type of diabetes	Gender (male %)	Study duration (months)	mHealth intervention (+ additional components)	Comparator condition	Outcomes measured	Outcomes tested as between-group analyses
Moattari *et al.*, 2013 (34)	Iran	RCT	52/48	18–39	Mostly type 1	43	3	Online platform containing personalized educational content and portal where patients entered daily data and received weekly feedback from physicians. Users could ask questions into the portal and receive answers from healthcare providers. Also involved chatroom with other users	Education advice as usual	HbA1c, fasting blood sugar, total cholesterol, triglycerides, HDL, LDL	HbA1c, fasting blood sugar, total cholesterol, triglycerides, HDL, LDL
Takenga *et al.*, 2014 (35)	The Democratic Republic of Congo	RCT	40/31	35–75	Type 2	72.5	2	Mobil Diab: Smartphone or web-based portal where patients uploaded data and received feedback (incl. therapy plans) from doctors SMS alerts were sent to doctors in emergency cases	Treatment as usual	Blood glucose, amplitude of glycaemic excursions, HbA1c	Nil
Zhou *et al.*, 2014 (36)	China	RCT	108/108	18–75	Type 2	Unspecified	3	Online portal where patients entered clinical and behavioural diabetes-related data at least once/fortnight. Personalized feedback received from staff through the portal, email, SMS and phone call Participants also attended educational session (same as control)	Treatment as usual + educational session	BMI, systolic and diastolic blood pressure, fasting blood sugar, HbA1c, total cholesterol, triglycerides, HDL, LDL, hypoglycemic episodes	BMI, systolic and diastolic blood pressure, fasting blood sugar, HbA1c, total cholesterol, triglycerides, HDL, LDL, hypoglycemic episodes
Kaur *et al.*, 2015 (37)	India	RCT (3 arms)	120/120	>18	Type 1 or Type 2	51	3	Weekly telephone consultations between patient and provider to review weekly glucose testing results Participants also attended out-patient visits	Out-patient visits	HbA1c, total cholesterol, HDL, LDL, triglycerides, fasting blood sugar, PPBS, adherence to medication, adherence to diet and exercise advice, emergency admissions	Fasting blood sugar, PPBS, HbA1c

Table 1 (*continued*)

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Author, year (ref)	Country	Study design	Sample size (baseline/ follow-up)	Age range (years)	Type of diabetes	Gender (male %)	Study duration (months)	mHealth intervention (+ additional components)	Comparator condition	Outcomes measured	Outcomes tested as between-group analyses
Lee *et al.*, 2015 (38)	Malaysia	RCT	37/32	18–75	Type 2	43	1.5	Online portal that transmitted patient data to providers. Data was obtained via web-enabled glucometer, which participants were asked to use 5 times/day. Patients received feedback following concerning glucose readings	Treatment as usual	Hypoglycemic episodes, fructosamine, total cholesterol, triglycerides, HDL, LDL, fasting plasma glucose	Hypoglycemic episodes, fructosamine, total cholesterol, triglycerides, HDL, LDL, fasting plasma glucose
Shahid *et al.*, 2015 (39)	Pakistan	RCT	440/440	18–70	Type 2	61.4	4	Fortnightly telephone consultations between patient and provider. During consultations, patients relayed their BG recordings and self-care behaviours over the preceding fortnight and received immediate feedback from the provider. Intervention participants were provided the same educational material and services as control patients	Treatment as usual + educational material	Hypertension, systolic and diastolic blood pressure, BMI, LDL, HbA1c, diet, physical activity	HbA1c
Anzaldo-Campos *et al.*, 2016 (40)	Mexico	RCT (3 arms)	201/201	18–75	Type 2	31	10	MyGlucoHealth: patients entered diabetes tracking data to an online portal via a web-enabled glucometer and electronic surveys. Providers viewed the portal and provided feedback to patients on their clinical and behavioural recordings. Providers were alerted to concerning readings Participants also received a care management plan by a multi-disciplinary team (same as control)	Care management plan delivered by multi-disciplinary team	HbA1c, total cholesterol, HDL, LDL, triglycerides, systolic and diastolic blood pressure, BMI, diabetes self-care behaviours	HbA1c, total cholesterol, HDL, LDL, triglycerides, systolic and diastolic blood pressure, BMI, diabetes self-care behaviours

Table 1 (*continued*)

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Author, year (ref)	Country	Study design	Sample size (baseline/ follow-up)	Age range (years)	Type of diabetes	Gender (male %)	Study duration (months)	mHealth intervention (+ additional components)	Comparator condition	Outcomes measured	Outcomes tested as between-group analyses
Zhou *et al.*, 2016 (41)	China	RCT	100/100	18–74	Type 1 or Type 2	57	3	Welltang smartphone app: patients uploaded self-care data and providers viewed the data and relayed personalized feedback (incl. medication regimes). Alerts sent to both patients and providers in instances of concerning readings	Treatment as usual	HbA1c, fasting blood glucose, postprandial blood glucose, LDL, weight, BMI, waist and hip circumference, systolic and diastolic blood pressure, self-care behaviours, hypoglycemic events	HbA1c, fasting blood glucose, postprandial blood glucose, LDL, weight, BMI, waist and hip circumference, systolic and diastolic blood pressure, self-care behaviours, hypoglycemic events
Kleinman *et al.*, 2017 (42)	India	RCT	90/80	18–65	Type 2	70	6	Gather Health: smartphone app for patients and a smartphone app + web portal for providers. Patients uploaded self-care data and providers provided feedback. Participants could contact providers through the online portal. Patients were reminded via the app to enter self-care data. Patients also received all the care/services provided to the control condition	Usual care, with free visits, laboratory tests, transportation fees, strips and lancets	HbA1c, BMI, waist circumference, blood pressure, fasting blood glucose, lipids, medication adherence, BG testing adherence	HbA1c, BMI, fasting blood glucose, medication adherence, BG testing adherence

RCT, randomized controlled trial; HbA1c, glycosylated haemoglobin; SMS, short message service; HDL, high-density lipoprotein; LDL, low-density lipoprotein; BMI, body mass index; PPBS, postprandial blood sugar; BG, blood glucose; App, application.

Table 2 Intervention effects by outcome measure

Outcome measure	Study	Intervention	Control	Effect size, P value
HbA1c (mean change in %)	Moattari *et al.* (34)	–2.03	–0.6	P<0.001*
	Zhou *et al.* (36)	–1.6	–0.62	P<0.01*
	Kaur *et al.* (37)	–0.5	–0.17	P=0.99
	Anzaldo-Campos *et al.* (40)	–3.02	–2.63	P=0.86
	Zhou *et al.* (41)	–1.95	–0.79	P<0.001*
	Kleinman *et al.* (42)	–1.5	–0.8	P=0.02*
HbA1c (% age of patients achieving target of <7%)	Zhou *et al.* (36)	66.04	47.27	Significant. P value not reported*
	Shahid *et al.* (39)	Not specified	Not specified	Adjusted RR =2.71; P=0.023*
FBS (mean change in mg/dL)	Moattari *et al.* (34)	–10.87	1.66	P=0.681
	Zhou *et al.* (36)	–30.1	–12.8	P<0.05*
	Kaur *et al.* (37)	–49.3	–41.75	P=0.71
	Zhou *et al.* (41)	–34.2	–17.3	P<0.01*
	Kleinman *et al.* (42)	–32.6	–23.5	P=0.55
PPBS (mean change in mg/dL)	Kaur *et al.* (37)	–62.7	–68.9	P=0.337
FPG (mean change in mmol/L)	Lee *et al.* (38)	0.1	1.4	P=0.112
LDL (mean change in mmol/L)	Moattari *et al.* (34)	–0.46	0.28	P<0.02*
	Zhou *et al.* (36)	0.02	–0.26	Not significant
	Lee *et al.* (38)	–0.1	-0.1	P=0.777
	Anzaldo-Campos *et al.* (40)	–0.022	–0.014	Not significant
	Zhou *et al.* (41)	–0.05	–0.08	Not significant
HDL (mean change in mmol/L)	Moattari *et al.* (34)	0.31	0.16	P=0.307
	Lee *et al.* (38)	0.1	0.1	P=0.887
	Zhou *et al.* (36)	0.04	0.0	Not significant
	Anzaldo-Campos *et al.* (40)	0.085	0.087	Not significant
Total cholesterol (mean change in mmol/L)	Moattari *et al.* (34)	0.21	–0.04	P=0.69
	Zhou *et al.* (36)	–0.08	–0.53	Not significant
	Lee *et al.* (38)	0.1	0.1	P=0.378
	Anzaldo-Campos *et al.* (40)	–0.76	–0.41	Not significant
Triglycerides (mean change in mmol/L)	Moattari *et al.* (34)	2.51	–0.44	P=0.336
	Zhou *et al.* (36)	–0.11	–0.07	Not significant
	Lee *et al.* (38)	0.5	0.3	P=0.421
	Anzaldo-Campos *et al.* (40)	–2.60	–1.66	Not significant
Fructosamine (mean change in µmol/L)	Lee *et al.* (38)	–19.4	–30	P=0.157

Table 2 (*continued*)

Table 2 (*continued*)

Outcome measure	Study	Intervention	Control	Effect size, P value
Hypoglycemic episodes (total n)	Zhou *et al.* (36)	7	14	P=0.044*
	Lee *et al.* (38)	88	157	OR =0.2, P=0.04*
	Zhou *et al.* (41)	2.34	2.43	Not significant
Weight (mean change in kg)	Zhou *et al.* (41)	–0.2	0.2	Not significant
BMI (mean change kg/m^2)	Zhou *et al.* (36)	0	0.11	Not significant
	Anzaldo-Campos *et al.* (40)	0.23	0.25	Not significant
	Zhou *et al.* (41)	–0.03	0.09	Not significant
	Kleinman *et al.* (42)	–0.1	0.1	P=0.53
Waist circumference (mean change in cm)	Zhou *et al.* (41)	0.0	0.0	Not significant
Hip circumference (mean change in cm)	Zhou *et al.* (41)	0.0	0.0	Not significant
SBP (mean change in mmHg)	Zhou *et al.* (36)	–4.02	–2.95	Not significant
	Anzaldo-Campos *et al.* (40)	–4.05	0.08	Not significant
	Zhou *et al.* (41)	–0.6	–2	Not significant
DBP (mean change in mmHg)	Zhou *et al.* (36)	–2.25	–1.84	Not significant
	Anzaldo-Campos *et al.* (40)	–3.74	0.14	Not significant
	Zhou *et al.* (41)	–1.0	–0.3	Not significant
Medication adherence (took all medication last week)	Kleinman *et al.* (42)	39.0	12.8	P=0.03*
BG testing (any last week)	Kleinman *et al.* (42)	39.0	10.3	P=0.01*
Diabetes self-care behaviours score:				
a) SDSCA	Anzaldo-Campos *et al.* (40)	14.44	14.08	Not significant
b) IMEVID	Zhou *et al.* (41)	15.8	10.2	P<0.01*

*, significant at P<0.05. RR, risk ratio; OR, odds ratio. HbA1c, glycosylated haemoglobin; FBS, fasting blood sugar; PPBS, post-prandial blood sugar; FPG, fasting plasma glucose; LDL, low-density lipoprotein; HDL, high-density lipoprotein; SBP, systolic blood pressure; DBP, diastolic blood pressure; BG, blood glucose; IMEVID, the Instrument to Measure Lifestyle of Type 2 Diabetes Mellitus Patients; SDSCA, Summary of Diabetes Self-Care Activities Measure.

Out of the five studies that analysed change in LDL, one study reported significantly greater improvement among the intervention group (reduction of 0.46 mmol/L) compared to control (increase of 0.28 mmol/L), with P<0.02 (34). Four studies reported no effect of the intervention on LDL (37,38,40,41). None of the included studies reported statistically significant intervention effects on any other clinical outcome measure (i.e., HDL, triglycerides, fructosamine, PPBS, fasting plasma glucose, total cholesterol, weight, BMI, waist and hip circumference, systolic and diastolic blood pressure).

Out of three studies that compared the number of self-reported hypoglycemic episodes between groups, two reported that the intervention groups experienced significantly fewer than the comparison groups: 88 *vs.* 157 episodes, with P<0.04 (38); and 7 *vs.* 14 episodes, with P<0.05 (36), whilst the third reported no difference (41).

The single study that tested the effect of the intervention on self-reported medication adherence, reported that a significantly greater number of people from the intervention group improved in taking all prescribed medication, compared to the control group (P=0.03) (42). The same study reported that the positive change in number of people testing blood glucose post-intervention was significantly

stronger among the intervention group, compared to control (P=0.01) (42).

Two studies compared the control and intervention groups on diabetes self-care behaviours over the course of the study using standardized multi-item scales (40,41). The study by Zhou *et al.* (41) reported significantly greater improvements on the Instrument to Measure Lifestyle of Type 2 Diabetes Mellitus Patients (IMEVID) among intervention participants (P<0.01), whilst the study by Anzaldo-Campos *et al.* (40) reported no between-group difference on the Summary of Diabetes Self-Care Activities Measure (SDSCA).

Intervention effects by intervention type

Five out of the seven studies that trialled variations of a mobile portal for transmitting information between patients and healthcare providers reported significant positive intervention effects on at least one measure of glycaemic control. Of these, four studies reported greater average reductions in HbA1c levels for the intervention group (34,36,41,42). The fifth study reported significantly fewer hypoglycemic episodes among the intervention group, compared to control (38), an effect also reported in the study by Zhou *et al.* (36). Other positive intervention effects included greater average reduction in fasting blood sugar levels (36), larger proportion of people achieving target HbA1c levels (36), and significantly better LDL change scores (34). Of these studies, three evaluated the intervention on diabetes self-care behaviours, with two observing positive intervention effects (41,42). Kleinman *et al.* reported significant intervention effects on medication adherence and blood glucose testing (42). Two studies administered multi-item measures to derive a total diabetes self-care score. Of these, Zhou *et al.* (41) observed significantly greater average improvements for the intervention group, compared to control, whereas Anzaldo-Campos *et al.* (40) reported no difference between groups. The studies by Anzaldo-Campos *et al.* (40) and Takenga *et al.* (35) did not observe positive intervention effects on any outcome measure, potentially due in part to the absence of between-group analyses on some or all outcome measures.

Of the two studies that trialled telephone consultations between patients and healthcare providers, the study by Shahid *et al.* (39) reported a significantly greater proportion of people achieving normal HbA1c levels in the intervention group, compared to control with an adjusted risk ratio =2.71 (P=0.023). The study by Kaur *et al.* (37) reported no effect of the intervention on any diabetes outcome measure.

Summary

In summary, six out of nine included studies reported significant, positive effects of the intervention on at least one clinical or self-reported measure of glycaemic control (34,36,38,39,41,42). The mHealth intervention was associated with greater reductions in HbA1c in four studies (34,36,41,42), fewer episodes of hypoglycemia in two studies (36,38), improved fasting blood sugar in one study (36), greater proportions of people achieving target HbA1c in two studies (36,39), improved LDL in one study (34), improvements in both medication adherence and blood glucose testing in one study (42), and improvements in overall self-care behaviour in one study (41).

Included studies were highly heterogeneous due to important differences in populations, interventions, study designs, outcomes and results. Based on this assessment, a meta-analysis was not undertaken.

Discussion

This review of published evidence for the effectiveness of mHealth interventions for diabetes care in LMICs, found that most of the included studies provide some evidence of a positive intervention effect on clinical diabetes-related outcomes. These results are somewhat consistent with the results of previous reviews, which have largely reported positive intervention effects (14,21,24,26,27). Whilst only three studies reviewed here investigated the effect of the mHealth intervention on key diabetes-related behavioural outcomes, two studies (41,42) reported positive intervention effects which were consistent with previous reviews (14,27).

In the current review, most studies where patients and healthcare providers exchanged information via an online portal, reported the intervention to be associated with greater improvement in blood glucose outcomes. This is consistent with a former review of this type of mHealth intervention in HICs, which reported positive intervention effects on pooled HbA1c (43). Thus, these types of mHealth interventions show promise in both low- and high-resource settings.

This review reported mixed evidence for an effect of telephone consultations between healthcare providers and patients on clinical diabetes outcomes. Previous reviews (9,24) reported that telephone consultations were associated with improved HbA1c levels, a conclusion only partially supported here. One previous review (9) found evidence supporting an effect of telephone consultations on diabetes

Table 3 Risk of bias assessment

Domain	Moattari *et al.* (34)	Takenga *et al.* (35)	Zhou *et al.* (36)	Kaur *et al.* (37)	Lee *et al.* (38)	Shahid *et al.* (39)	Anzaldo-Campos *et al.* (40)	Zhou *et al.* (41)	Kleinman *et al.* (42)
Random sequence generation	√	?	√	√	?	X	?	?	√
Allocation concealment	?	?	?	?	?	?	?	?	√
Blinding of participants and personnel	?	?	?	?	?	X	?	?	?
Blinding of outcome assessment	√	X	?	?	?	?	?	?	√
Incomplete outcome data	√	X	X	√	?	√	√	?	?
Selective reporting	X	X	√	X	X	X	√	?	X

√, low risk; X, high risk; ?, unclear risk.

self-care behaviours, whilst another reported no effect (24). Neither of the two studies that evaluated telephone consultations in this review reported testing behavioural outcomes, which impeded conclusions about such outcomes.

The present review demonstrates promising, albeit limited evidence for the effectiveness of mHealth interventions on glycaemic control in LMICs. Furthermore, the review process identified several additional studies of mHealth applications for diabetes care in LMICs which were excluded because of study design, failure to report on any of the outcome measures, or were research protocols (44-46). Thus, there is evidence of additional mHealth interventions for diabetes care in LMICs other than those reviewed here. In addition, a survey conducted by the World Health Organization indicated that as few as 12% of mHealth initiatives are evaluated (47). Therefore, there is great opportunity to add to the evidence base by conducting evaluations of existing and proposed mHealth applications using rigorous study designs and assessing effectiveness on key diabetes outcome measures, both clinical and behavioural.

Several limitations of this review warrant consideration. Firstly, all included studies suffered from multiple methodological or reporting weaknesses. A detailed analysis of included studies' performance on each domain of the Cochrane Collaboration's risk of bias assessment tool is summarised in *Table 3*. Overall, the brevity with which study methods were described made it difficult to assess all the studies on at least two domains of the tool. Randomization procedures, methods for concealing allocation procedures and processes for handling missing data/participant dropout in analyses were generally poorly described. While most studies reported the baseline characteristics for each group separately, three studies did not establish group equivalence at baseline (34,35,38). Several studies (35,38) also failed to report testing some or all outcome measures as between-group comparisons, which was contradictory to their study design.

This review has established that further studies in this field are needed. Future studies should deliver standard and equivalent care to all study participants apart from the trialled mHealth intervention. Additionally, studies should conduct and report the results of appropriate between-group analyses on all measured outcomes, including at baseline, to enable a comprehensive assessment of the intervention's effectiveness as well as adverse effects.

Additionally, given the chronicity of diabetes, future studies should also evaluate mHealth interventions over longer treatment and follow-up periods. There is widespread recognition that patients face many barriers to making behavioural changes to improve diabetes outcomes (48). Greater exposure to the intervention may give participants more opportunity to understand, adapt to and integrate the new program into their lives.

This review reported on just one study that included a sample of people with mostly type 1 diabetes (34). This review found preliminary evidence that the effects of mHealth interventions may differ according to type of diabetes. Thus, future studies should examine the effects of mHealth interventions on people with type 1 as well as type 2 diabetes either in separate studies or reporting on the outcomes separately to allow for comparison.

In addition, analyzing the effect of the intervention on both behavioural diabetes self-care practices (e.g., diet, exercise, blood glucose monitoring and medication adherence) and clinical outcome measures within the one study is recommended to determine whether intervention effects on glycaemic control occur irrespective of impact on behaviour change. Furthermore, evaluating both types of outcomes over longer periods may elucidate change trajectories, for instance, behaviour change preceding changes in clinical markers. In addition, given that a key justification for developing mHealth interventions is their cost-saving potential, future studies should assess cost effectiveness.

Conclusions

This review synthesized the current evidence for the effectiveness of mHealth interventions for diabetes management in LMICs and highlighted numerous research gaps and methodological challenges in the existing research. The findings demonstrate that there is promising, albeit limited evidence that mHealth interventions in LMICs can have positive effects on glycaemic control and self-care behaviours. However, the field of mHealth for diabetes management in LMICs is still in its infancy, and there is a dearth of experimental studies adequately evaluating these interventions on key clinical or behavioural outcomes. This highlights the need for more rigorous evaluation of these interventions to provide a stronger research base for policy makers and clinicians.

Acknowledgments

Sincere thanks go to Nicole Butcher for providing detailed editing of the document in preparation for submission.
Funding: None.

Footnote

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/jhmhp.2018.07.01). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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doi: 10.21037/jhmhp.2018.07.01
Cite this article as: Johnston L, Zemanek J, Reeve MJ, Grills N. The evidence for using mHealth technologies for diabetes management in low- and middle-income countries. J Hosp Manag Health Policy 2018;2:35.

