

Effectiveness of digital health interventions for diabetes: Systematic review of systematic reviews

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Abstract

Introduction: The use of digital health technologies to tackle diabetes has been particularly flourishing in recent years. Previous studies have shown to varying degrees that these technologies can have an impact on diabetes prevention and management. The objective of this review is to summarize the best evidence regarding the effectiveness of digital health interventions to improve one or more diabetes indicators.

Methods: We included all types of interventions aimed at evaluating the effect of digital health on diabetes. We considered at all types of digital interventions (mobile health, teleconsultations, tele expertise, electronic health records, decision support systems, e-learning, etc.). We included systematic reviews published in English or French over the last 29 years, from January 1991 to December 2019 that met the inclusion criteria. Two reviewers independently reviewed the titles and abstracts of the studies to assess their eligibility, and extracted relevant information according to a predetermined grid. Any disagreement was resolved by discussion and consensus between the two reviewers, or involved a third author as referee.

Results: We included 10 reviews in total. The outcomes of interest were clinical indicators of diabetes that could be influenced by digital interventions. These outcomes had to be objectively measurable indicators related to diabetes surveillance and management that are generally accepted by diabetes experts. Six of the ten reviews showed moderate to large significant reductions in glycated haemoglobin (HBA1c) levels compared to controls. Most reviews reported overall positive results and found that digital health interventions improved health care utilization, behaviours, attitudes, knowledge and skills.

Conclusion: Based on a large corpus of scientific evidence on digital health interventions, this over view could help identify the most effective interventions to improve diabetes indicators.

Keywords: Diabetes; Digital health; E-Health interventions; Diabetes indicators; M-Health

Introduction

According to the International Diabetes Federation (IDF), 425 million people were living with diabetes in 2017 and by 2045 this figure will rise to 628 million people, more than 80% in low and middle income countries.¹ According to recent projections of global mortality world-wide, diabetes will become the 7th leading cause of death by 2030.² The prospects in terms of solutions to fight diabetes remain a topical issue for all stakeholders (scientists, professionals, decision makers and patients). For several experts, new technologies are now presenting themselves as a credible solution.³ The WHO is on the front line and some countries such as France have taken the lead by legislating.^{4,5} Today, the Internet is a widely accessible means of promoting health and managing chronic diseases. The number of scientific publications on digital health has increased considerably over the last decade, based on the use of the internet, mobile phones and computers to support lifestyle changes for people living with diabetes.⁶⁻¹⁰

A systematic review of Internet focused interventions aimed to identify Internet based lifestyle modification interventions in adults with type 2 diabetes demonstrated an improvement in diet and metabolic indicators in diabetic patients.¹¹ Two meta-analyses, coupled with a narrative report of randomized controlled trials, examined the use of digital health to improve self-management skills and evaluated the effect of mobile phone interventions on glycaemic control in people with diabetes.^{12,13} They found an improvement in self-management skills and documented an average decrease in glycosylated haemoglobin of 0.14% and blood glucose of 0.33 mmol. Two other systematic reviews have been identified, one based on online programs and the use of technology to promote physical activity in T2DM.^{14,15} These reviews sought to identify behaviour change techniques (BCTs) that are applied in web based self-management and physical activity promotion programs and their effectiveness in relation to predefined health outcomes. Based on their results, it appears that it is still difficult to know which BCTs are effective in improving diabetes self-management and physical activity. Other studies have focused on specific technologies (e.g. telemedicine, decision support tool, electronic medical record) to support diabetes care. However, evaluation of these interventions to improve the quality of diabetes care in low resource countries is largely lacking.

Over the past 30 years, the effectiveness of digital health interventions in the field of diabetes has been assessed. Our aim is to synthesize this large body of evidence to demonstrate the importance of digital health in the pre-

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vention and management of diabetes. Conducting a systematic review of systematic reviews will allow summarizing and analysing the scientific evidence regarding the surveillance, treatment and prevention of diabetes complications.

Methods

Epidemiological studies have been conducted to describe the characteristics of Digital health based interventions and identify those associated with diabetes. Several of these studies used data from pilot interventions. However, most of them sought factors positively associated with the management and prevention of diabetes related complications through cross sectional analyses, i.e. comparing users and Digital health solutions at inclusion or over a given period of time. Although a few longitudinal analyses have focused on factors preventing complications or glycaemic control in people with diabetes.

Sources of Information

As a first step, we conducted bibliographic searches on PubMed® and Google Scholar. Several terms related to the effectiveness of digital health interventions for diabetes were searched. Papers published between January 1990 and December 2019 was considered. In a second step, we searched the references listed in the articles collected through previous searches.

Eligibility criteria

We included systematic reviews that evaluated and described the effects of digital health on diabetes management indicators, regardless of the type of diabetes and the type of interventions. Those published in English or French over the last 30 years (1991-2019), since we considered that the Internet was not widely available prior to 1991. Reviews clearly describing the method used to select studies were selected. We included reviews that used systematic search strategies to identify the selected studies, had a systematic presentation, and provided a summary of the results and main characteristics of the included studies.

Selection process

Following the final decision to include the studies in the review, data extraction was performed by two independent individuals. We used a data collection form (AM-STAR) that allowed us to collect all of the data needed to analyse the studies, such as eligibility criteria, methods and participants, interventions, judging criteria or outcomes. Risks of bias were also extracted in order to assess the level of evidence for each study. Once all the data was extracted and collected in the collection form, we used Microsoft Excel data management software to prepare the data analysis.

Data extraction and analyses

We produced a synthesis table for each included systematic review. It indicated the references of the articles (author, year, name of the journal), the objective of the study, the

study population, the methods used, the definition of the variables of interest, the exposure variables, the main and secondary results, the limitations of the study as well as any comments related to the study (adjustments, definitions, classifications used). Given the length of the table and by way of example, an extract concerning two selected articles is available in supplementary data. A first table presenting the authors, the types of intervention, technologies and the number of participants in each retention were produced Figure 1.

Results

The first query had yielded 7761 results. The same date query at Google Scholar after excluding duplicates yielded 4230 results. After reading titles and abstracts, 117 publications were retained as potentially relevant to this study and were read in full. A total of 10 full text articles were selected.

Teen systematic reviews were included in our review. Nearly 74% of the reviews showed an additional form of benefit linked to the use of digital health. Conversely, 13% of the reviews were unable to clearly define the additional benefit linked to digital health.¹⁶ Information technologies used in the studies included the Internet (47%), cellular telephones (32%), telemedicine (12%) and decision support systems (9%).¹² There are also notable advantages i.e. user friendliness, real time feed-back, integration of Digital health with the medical system, improved analytical and decision support capabilities. According to the review authors, these studies have limitations including the heterogeneity of methods, disparity of results, failure to take into account specificities such as minorities, and methodological difficulties related to the study of particular cases.

Section 3.01 clinical outcomes and ICT use in health care

Among included reviews, there were 22 trials that made reference to clinical data and digital health: Internet, telephone, computer assisted integration of clinical data information.^{12,17}

The results of the Meta analyses of 14 interventions revealed that digital health use was associated with significant reductions in HbA1c levels, blood pressure, total cholesterol, and triglycerides compared with usual care. A meta-analysis involving 1657 participants showed that mobile phone diabetes self-management interventions reduced HbA1c values by a mean of 0.5% [6 mmol/l; 95% Confidence Interval, 0.3%-0.7% (4-8 mmol/l)] over a median follow up time of 6 months.¹³

In subgroup analysis, 10 reviews targeting patients with type 2 diabetes reported significantly greater reductions in HbA1c than studies in patients with type 1 diabetes [0.8 (9 mmol/l) vs. 0.3% (3 mmol/l); P=0.02]. The effect of the mobile phone intervention did not differ significantly from other participant characteristics or intervention strategies. Another review of 40 studies, in which glycated haemoglobin, and blood glucose levels were reported, showed significant improvement in 7 and 6 trials, respectively.¹⁸

A significant improvement in compliance was found in 6 of the 8 computerized incentive studies. Meta-analysis of studies using home blood glucose records in insulin dose adjustment documented a mean decrease in glycat- ed haemoglobin of 0.14 mmol/L (95% CI, 0.11-1.16), and a decrease in blood glucose of 0.33 mmol/L (95% CI, 0.28- 0.39).¹⁹ several computerized educational programs im- proved metabolic indicators.

One of the included reviews had retained only 9 stud- ies based on its inclusion criteria. Of the 9, two studies demonstrated improvements in glycaemic control.

Dietary outcomes and behavioral changes

Several computer based educational programs have been shown to significantly improve the diets and behaviours of people living with diabetes, particularly type 2 diabe- tes.^{11,17} We identified a review of 37 included studies, in-

cluding 13 trials, based on the link between ICT and diet and behaviour change.¹⁵ In the same review cited above, which focused on randomized trials, improvements in diet and/or physical activity were found in comparison with a control group (Table 1). Successful studies were interactive components based on theory, with personal- ized follow up and feedback, and provided opportunities for peer support. Use of the site decreased over time in all studies. Few studies focused on high risk and under- served populations.¹⁴

In another review, which included 15 eligible studies, interventions were delivered through Internet, mobile phone, CD-ROM and computer.²⁰ These studies showed an increase in physical activity, but only nine were signifi- cant (Tables 2 and 3).

Table 1: Classification according to the overall outcomes

N°	Auteurs	Primary Outcomes	Intervention/ Type of technologies	Number partici- pants
1	Or & Tao 2014	Patient self-manage- ment of diabetes	Consumer health information technol- ogies (CHITs	Sixty-two studies, representing 67 RCTs, met the inclu- sion criteria
2	Cotter et al 2013	Among adults with type 2 diabetes.	Internet based inter- ventions to promote lifestyle modification	Of the 2803 papers identified, nine met inclusion criteria.
3	Connely et al 2013	Type 2 diabetes	Technology includ- ed mobile phones and text messages, websites, CD-ROMs and computer-learn- ing-based technol- ogy,	In total, 15 articles were eligible for review
4	Van Gugt et al 2013	Diabetes self-man- agement behaviours and related health outcomes	Online diabetes self-management tools and programs,	Among 40 eligible studies,
5	Omar El-Gayara et al 2013,	Self-management for Type 1 and Type2 diabetes	Information technol- ogy	A total of 104 studies were included..
6	Ali et al 2011	Physician perfor- mance and patient outcomes	Applicability in LMICs	33 studies met inclu- sion criteria

Review Article

7	Liang et al 2010	Diabetes or diabetes Mellitus	Mobile phone or cellular phone, or text message	A total of 22 trials were selected for the review.
8	Dalton et al 2008	Telediabetes is a form of telemedicine used to provide information and client care to people with diabetes.	Cellular telephones and/or computers	Nine articles meeting the inclusion criteria were identified, critiqued, and summarized.
9	Jacksson et al 2006	Type 2 diabetes	Information Technology (IT)	There were 26 studies.
10	Balas et al 2004	Patient outcomes and to enable this knowledge to be incorporated into diabetes care practice	automated information interventions on diabetes	Among 40 eligible studies,

Table 2: Clinical Outcomes and the Use of Digital health in Health Care

Objective	Outcome	Number of studies included	Summary of results	Authors' conclusions
To synthesize evidence from randomized controlled trials (RCTs) on the effects of Consumer health information technologies (CHITs) on patient outcomes	Patient self-management of diabetes	Sixty-two studies, representing 67 RCTs, met the inclusion criteria	The results of the meta-analyses showed that the use of CHITs was associated with significant reductions in HbA1c, blood pressure, total cholesterol, and triglycerides levels when compared with usual care. The findings from the narrative synthesis indicated that only a small proportion of the trials reported positive effects of CHITs on patient outcomes.	
To determine how IT has been used to improve self-management for adults with Type 1 and Type2 diabetes.	self-management for Type 1 and Type2 diabetes	A total of 104 studies were included..	Overall, 74% of studies showed some form of added benefit, 13% articles showed no-significant value provided by IT, and 13% of articles did not clearly define the added benefit due to IT. Information technologies used included the Internet (47%), cellular phones (32%), telemedicine (12%), and decision support techniques (9%). Limitations and research gaps identified include usability, real-time feedback, integration with provider electronic medical record (EMR), as well as analytics and decision support capabilities.	

<p>To assess the effect of mobile phone intervention on glycaemic control in diabetes self-management</p>	<p>Diabetes or diabetes Mellitus 1657 participants showed that mobile phone interventions for diabetes self-management</p>	<p>A total of 22 trials were selected for the review.</p>	<p>Meta-analysis among 1657 participants showed that mobile phone interventions for diabetes self-management reduced HbA1c values by a mean of 0.5% [6 mmol/mol; 95% confidence interval, 0.3–0.7% (4–8 mmol/mol)] over a median of 6 months follow-up duration. In subgroup analysis, 11 studies among Type 2 diabetes patients reported significantly greater reduction in HbA1c than studies among Type 1 diabetes patients [0.8 (9 mmol/mol) vs. 0.3% (3 mmol/mol); P = 0.02]. The effect of mobile phone intervention did not significantly differ by other participant characteristics or intervention strategies</p>
<p>To determine how emerging interactive IT has been used to enhance care for adults with type 2 diabetes.</p>	<p>type 2 diabetes The median (range) sample size was 165 (28 to 6,469 participants) for patients and 37 (15 to 67) for providers;</p>	<p>There were 26 studies.</p>	<p>(27 reports): internet (n=6; 3 RCTs), telephone (n=7; 4 RCTs), and computer-assisted integration of clinical information (n=13, 7 RCTs). the median duration was 6 (1 to 29) months. Ethnic minorities or underserved populations were described in only 8 studies. Six of 14 interventions demonstrated moderate to large significant declines in hemoglobin A1c levels compared with controls.</p>
<p>To identify the impact of automated information interventions on diabetes</p>	<p>Patient outcomes and to enable this knowledge to be</p>	<p>Among 40 eligible studies,</p>	<p>Glycated hemoglobin and blood glucose levels were significantly improved in 7 and 6 trials, respectively.</p>
<p>care and patient outcomes and to enable this knowledge to be incorporated into diabetes care practice.</p>	<p>incorporated into diabetes care practice</p>		<p>Significantly improved guideline compliance was reported in 6 of 8 computerized prompting studies. Three of 4 pocket-sized insulin dosage computers reduced hypoglycemic events and insulin doses. Metaanalysis of studies using home glucose records in insulin dose adjustment documented a mean decrease in glycated hemoglobin of .14 mmol/L (95% confidence interval _CI_ 0.11– 0.16) and a decrease in blood glucose of .33 mmol/L (95% CI, 0.28–0.39). Several computerized educational programs improved diet and metabolic indicators.</p>

Table 3: *Eating Outcomes and Behavior Changes*

Objective	Outcome	Number of studies included	Summary of results	Authors' conclusions
To provides a systematic and descriptive assessment of the effectiveness of technology to promote physical activity in people with Type 2 diabetes.	Type 2 diabetes	In total, 15 articles were eligible for review	web-based (9), mobile phone (3), CD-ROM (2) and computer based (1). All studies found an increase in physical activity but only nine were significant. The use of a personal coach, logbooks and reinforcement strategies such as phone calls and email counselling were found to be effective components for behaviour change. No studies were ranked as low in terms of methodological quality.	Technology-based interventions to promote physical activity are effective; using further methods to promote participant adherence is associated with greater benefit. Further research should look into strategies to enhance adherence and sustainability in order to increase the effectiveness of technology-based physical activity intervention in diabetes care.
The Internet presents a widely accessible, 24-h means to promote chronic disease management. The objective of this review is to identify studies that used Internet based interventions to promote lifestyle modification among adults with type 2 diabetes.	Among adults with type 2 diabetes.	Of the 2803 papers identified, nine met inclusion criteria.	Two studies demonstrated improvements in diet and/or physical activity and two studies demonstrated improvements in glycemic control comparing web-based intervention with control. Successful studies were theory-based, included interactive components with tracking and personalized feedback, and provided opportunities for peer support. Website utilization declined over time in all studies that reported on it. Few studies focused on high risk, underserved populations.	Web-based strategies provide a viable option for facilitating diabetes self-management. Future research is needed on the use of web-based interventions in underserved communities and studies examining website utilization patterns and engagement over time.

To identify which BCTs are being applied in online self-management programs for T2DM and whether there is indication of their effectiveness in relation to predefined health outcomes.

diabetes self-management behaviors and related health outcomes

They found 13 randomized controlled trials reporting on 8 online self-management interventions for T2DM. The BCTs used were feedback on performance, providing information on consequences of behavior, barrier identification/problem solving, and self-monitoring of behavior. These BCTs were also linked to positive outcomes for health behavior change, psychological well-being, or clinical parameters.

Relatively small number of theory-based online self-management support programs for T2DM have been reported using only a select number of BCTs. The development of future online self-management interventions should be based on the use of theories and BCTs and should be reported accurately.

To assess the quantifiable and qualitative impacts of combined EMR-CDSS tools on diabetes

Physician performance and patient outcomes

33 studies met inclusion criteria

Among predominantly experimental study designs, process improvements were consistently observed along with small, variable improvements in risk-factor control, compared with baseline and/or control groups (where applicable).

To review current research on online information for adults with type 2 diabetes. To determine the potential impact of this mode of dissemination on professional dietetic practice.

Telediabetes is a form of telemedicine used to provide information and client care to people with diabetes.

Nine articles meeting the inclusion criteria were identified, critiqued, and summarized.

Studies varied greatly in breadth and scope; consequently, few general conclusions could be drawn about telediabetes programs. Telediabetes programs were discussed in the context of soundness, effectiveness, cost-effectiveness, and practical characteristics. Trends indicated a promising future for telediabetes

Dietitians should view telemedicine as a viable tool for service delivery and increase their knowledge, competency, advocacy, and research efforts in this area.

Discussion

This review of systematic reviews provides a state of the art on the issue of the effectiveness of digital health in the monitoring and prevention of diabetes. To date, we find many reviews and studies on the use of digital health in diabetes around the world, but few studies seem to highlight the use of Digital health in Africa on non-communicable diseases, particularly diabetes.

The data were synthesized in a qualitative and descriptive manner. We did not conduct a meta-analysis, as the set of studies was not homogeneous. For this reason, we opted for a descriptive synthesis. One of the limitations of the chosen methodology could be completeness, as it is quite possible that published or unpublished evidence may not have been uncovered either due to lack of access.

The combined results of the included trials have provided strong evidence that a mobile phone intervention can lead to statistical analysis significantly improving glycaemic control and self-management in the treatment of diabetes, particularly in patients with type 2 diabetes.⁶ This review reinforces the need for well-designed surveys to assess the role and feasibility of interventional technologies in clinical decision making for diabetes care.

The results of this review consolidate the growing body of knowledge that emerging Digital health can improve the prevention and management of diabetes related diseases. Digital health is a rapidly developing tool in improving the care process for patients with type 2 diabetes, as these significant healthcare outcomes indicate.¹²

These results must be put into perspective with respect to the decrease in HbA1c levels and other clinical outcomes (i.e. lipids).²¹ Although these findings are consistent with reviews of type 1 diabetes in terms of psychological and biological outcomes, a formal meta-analysis conducted primarily in type 1 diabetes supports the hypothesis that computer systems can effectively improve metabolic control.²²

Internet assisted diabetic patients, usually focused on education, should assess their HbA1c, health care utilization and costs associated with the intervention.¹¹ by mode of delivery, Internet based interventions have a positive impact on patient centred outcomes. Unfortunately, however, they have not been evaluated in health care utilization and clinical outcomes. Telephone interventions had a positive impact on primary care visits. Computer assisted integration of clinical management also had a positive impact on most health care utilization outcomes.^{10,23} while several interventions resulted in significant reductions in HbA1c, there was no clear pattern by mode, and many studies reported no significant change in HbA1c.

A review by Farmer et al. evaluated the feasibility, acceptability and effectiveness of telemedicine used to support self-monitoring of blood glucose levels by transmitting results from a server with automated or clinician feedback.⁶ The results judged telemedicine to be feasible and accept-

able, but the evidence for its effectiveness in improving diabetes management was not considered strong. Although the main objective of the review and the inclusion/exclusion criteria led to a set of studies, which differed from this review, the results are consistent with our findings related to telemedicine interventions and HbA1c.

Computerized knowledge management is becoming a vital component of quality diabetes care. It promotes procedure monitoring, computerized adjustment of home insulin therapy, blood glucose records, remote feedback and documented advice benefits of improved diabetes outcomes.^{11,24,25} There is growing evidence that information technology can improve diabetes care. Future research should characterize the long term benefits, establish methods to evaluate clinical outcomes and determine the cost-effectiveness of ICT use.

There is a clear need for more comprehensive interventions, in which multiple technologies are integrated, to manage chronic diseases such as diabetes. These digital interventions should be theoretically based, and based on user centred socio technical design principles, in their planning, design, and implementation. The effectiveness of self-management systems should be evaluated according to several main criteria: motivation for self-management, long term adherence, cost, uptake, satisfaction, and outcomes as an end result. The use of digital health in supporting diabetes self-management appears to have potential benefits for patient self-management of diabetes. However, the effectiveness of technologies to improve patient outcomes is still awaiting confirmation in future studies.

In a context of limited resources, individual economic difficulties, lack of structured systems or skilled human capital in Africa, digital health can be a credible alternative for improving diabetes management. However, future research is needed on the use of digital health interventions in under-served communities, examining patterns of use and user engagement over time. Today, digital technologies are increasingly present in the health field. In Africa, the adoption of new technologies has had undeniable positive effects on the socio-economic development of the continent, the most striking example being mobile telephony. According to a 2013 study by the World Association of Telecom Operators (GSMA), the number of mobile subscribers in Africa grew by almost 20% per year between 2007 and 2012.

Digital health has the potential to improve care for chronic diseases, provide better health outcomes and reduce direct and indirect costs. However, realizing these gains requires new forms of care delivery through the adoption of new technologies. Achieving these new modes of delivery requires appropriate payment policies. Future authors should review the literature on health care payment and Digital health in chronic care and then apply a specific theoretical economic analysis of how Digital health is changing health care payment policy recommendations.²⁶

Primary and secondary prevention is a major focus in the fight against diabetes, in line with the over-all objective of promoting good behaviour in terms of diet and physical activity among people at risk or with diabetes. Digital health offers interesting perspectives with the benefit of reaching the greatest number of people and on a continuous basis. A relatively small number of online self-management support programs for WD2 have been reported using only a selected number of behaviours (physical activity, diet). Technology based interventions to promote physical activity are effective. Methods to promote participant adherence is associated with greater benefit. The development of future online self-management interventions should be based on the use of theories, and behaviour changes should be accurately reported. Future research should focus on strategies to improve adherence and sustainability to increase the effectiveness of technology based physical activity interventions in diabetes treatment.²⁷⁻³⁷

Conclusion

This review allowed us to synthesize and update information on the use of digital health in diabetes management and monitoring, and to provide several implications for future research. Our review suggests that digital health could be an important tool and should be further evaluated for its potential to improve diabetes care. On the other hand, studies should consider participants' perceptions of diabetes self-management, as digital health can likely be a component of care that depends on patient acceptance. There is also a need to improve the quality of studies and the communication of results.

Based on this review, we strongly recommend that future studies, particularly in Africa, should:

Favour designs that allow comparisons with a concurrent control group with a less biased assessment of the effectiveness of these interventions.

Study the long term effects of these interventions.

Address and report on the costs associated with the intervention and the resulting cost effectiveness.

Include a representative number of minorities and underserved populations and determine whether these interventions are equally effective in these groups.

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Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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