Effectiveness, reach, uptake, and feasibility of digital health interventions for adults with type 2 diabetes: a systematic review and meta-analysis of randomised controlled trials

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Summary

Background Digital health interventions have shown promising results for the management of type 2 diabetes, but a comparison of the effectiveness and implementation of the different modes is not currently available. Therefore, this study aimed to compare the effectiveness of SMS, smartphone application, and website-based interventions on improving glycaemia in adults with type 2 diabetes and report on their reach, uptake, and feasibility.

Methods In this systematic review and meta-analysis, we searched CINAHL, Cochrane Central, Embase, MEDLINE, and PsycInfo on May 25, 2022, for randomised controlled trials (RCTs) that examined the effectiveness of digital health interventions in reducing glycated haemoglobin A_{1c} (HbA_{1c}) in adults with type 2 diabetes, published in English from Jan 1, 2009. Screening was carried out using Covidence, and data were extracted following Cochrane's guidelines. The primary endpoint assessed was the change in the mean (and 95% CI) plasma concentration of HbA_{1c} at 3 months or more. Cochrane risk of bias 2 was used to assess risk of bias. Data on reach, uptake, and feasibility were summarised narratively and data on HbA_{1c} reduction were synthesised in a meta-analysis. Grading of Recommendations, Assessment, Development, and Evaluation criteria was used to evaluate the level of evidence. The study was registered with PROSPERO, CRD42021247845.

Findings Of the 3236 records identified, 56 RCTs from 24 regions (n=11 486 participants), were included in the narrative synthesis, and 26 studies (n=4546 participants) in the meta-analysis. 20 studies used SMS as the primary mode of delivery of the digital health intervention, 25 used smartphone applications, and 11 implemented interventions via websites. Smartphone application interventions reported higher reach compared with SMS and website-based interventions, but website-based interventions reported higher uptake compared with SMS and smartphone application interventions. Effective interventions, in general, included people with greater severity of their condition at baseline (ie, higher HbA_{1c}) and administration of a higher dose intensity of the intervention, such as more frequent use of smartphone applications. Overall, digital health intervention group participants had a –0·30 (95% CI –0·42 to –0·19) percentage point greater reduction in HbA_{1c}, compared with control group participants. The difference in HbA_{1c} reduction between groups was statistically significant when interventions were delivered through smartphone applications (–0·42% [–0·63 to –0·20]) and via SMS (–0·37% [–0·57 to –0·17]), but not when delivered via websites (–0·09% [–0·64 to 0·46]). Due to the considerable heterogeneity between included studies, the level of evidence was moderate overall.

Interpretation Smartphone application and SMS interventions, but not website-based interventions, were associated with better glycaemic control. However, the studies' heterogeneity should be recognised. Considering that both smartphone application and SMS interventions are effective for diabetes management, clinicians should consider factors such as reach, uptake, patient preference, and context of the intervention when deciding on the mode of delivery of the intervention. Nine in ten people worldwide own a feature phone and can receive SMS and four in five people have access to a smartphone, with numerous smartphone applications being available for diabetes management. Clinicians should familiarise themselves with this modality of programme delivery and encourage people with type 2 diabetes to use evidence-based applications for improving their self-management of diabetes. Future research needs to describe in detail the mediators and moderators of the effectiveness and implementation of SMS and smartphone application interventions, such as the optimal dose, frequency, timing, user interface, and communication mode to both further improve their effectiveness and to increase their reach, uptake, and feasibility.

Funding EU's Horizon 2020 Research and Innovation Programme.

Lancet Digit Health 2023; 5: e125–43

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Research in context

Evidence before this study

Digital health interventions can be effective for self-management of type 2 diabetes. Education, feedback, and communication between health-care providers and people with type 2 diabetes are key determinants of the effectiveness of digital health interventions. However, it is not known how the different modes of delivery of digital health interventions, such as smartphone applications, SMS, and websites, compare in terms of their effectiveness in reducing glycated haemoglobin A_{1c} (HbA_{1c}), as well as in terms of reach, uptake, and feasibility of interventions in people with type 2 diabetes. We searched CINAHL, Cochrane Central, Embase, MEDLINE, and PsycInfo on May 25, 2022, for randomised controlled trials (RCTs) that examined the effectiveness of digital health interventions in reducing HbA_{1c} in adults with type 2 diabetes, published in English from Jan 1, 2009. We identified 56 RCTs from 24 regions (n=11 846 participants) that were included in the narrative synthesis, of which 26 studies (n=4546 participants) were included in the meta-analysis. We conducted subgroup meta-analysis by mode of delivery to compare the effectiveness of interventions in reducing HbA_{1c}.

Added value of this study

To our knowledge this is the first meta-analysis to compare the clinical effectiveness and implementation of different modes of delivery of digital health, to facilitate clinicians' decisions. We identified that SMS and smartphone application interventions were associated with increased improvements in glycaemic control as well as a higher participant reach, compared with website-based interventions.

Implications of all the available evidence

Considering that 92% of the global population have a feature phone and can receive SMS and that 86% have access to a smartphone, and that numerous smartphone applications are currently available for people with type 2 diabetes, clinicians should familiarise themselves with this modality of programme delivery and encourage people with type 2 diabetes to use evidence-based applications and SMS interventions for improving their self-management of diabetes. Given the effectiveness of SMS and smartphone application interventions and their growing trend, clinicians can leverage the high penetration rates and reach in diverse populations to deliver interventions. This approach is of particular importance for rural and remote populations with limited health services and where diabetes prevalence is higher. Future research needs to describe in detail the mediators and moderators of the effectiveness and implementation of SMS and smartphone application interventions, such as the optimal dose, frequency, timing, user interface, and communication mode to both further improve their effectiveness and to increase their reach, uptake, and feasibility.

Introduction

Type 2 diabetes affects an estimated half a billion people worldwide,[1] with a cost in excess of US$1·3 trillion per annum.[2] The risk of adverse outcomes in people with type 2 diabetes and the cost of managing this condition can be reduced by lowering blood glucose levels, in addition to correcting hypertension and dyslipidaemia.[3] Current guidelines recommend that adults with type 2 diabetes should reach a glycated haemoglobin A_{1c} (HbA_{1c}) of less than 7·0% (53 mmol/mol) as part of their glycaemic control.[4]

Self-management, education and support have been recommended to enhance individuals' knowledge, skills, and the tools needed for the successful sustainable control of their clinical condition.[5] Digital health interventions present a feasible and effective means of type 2 diabetes self-management.[6–8] Since the introduction of the first smartphone in 1994,[9] mobile phones have rapidly evolved to allow for a plethora of diverse capabilities to facilitate health education and support of self-management.

As of January, 2023, 6·92 billion people in the world (86%) have access to a smartphone, and another 410 million people use a conventional mobile phone, accounting together for 92% of the global population.[10] Telehealth can also be more convenient and accessible than traditional face-to-face health-care delivery, because it can be delivered synchronously or asynchronously.[11]

Synchronous refers to the delivery of health information in real time (eg, via a telephone call) and asynchronous refers to the store-and-forward technique of health information—ie, the transmission of health information from the health-care provider to a patient (eg, via SMS). Synchronous interventions can use telephone or video-conference calls as well as mobile phone applications that collect clinical data, such as blood glucose or blood pressure, and transmit these in real time allowing for the health-care professional to provide prompt advice about titrating and adjusting medications such as insulin.[12] Synchronously delivered social media interventions can also use online forums in which patients can engage with peers, discuss the challenges they are facing, and interact with health-care professionals in real time, facilitating the identification of barriers and enablers to successful glycaemic control.[12] Asynchronous interventions use SMS to reinforce appropriate behavioural changes—eg, performing adequate physical activity, eating a sufficient amount of vegetables, or using online tools that provide general condition-specific education.[12]

Previous reviews have highlighted key determinants of the effectiveness of digital health interventions such as education, feedback, and communication between health-care provider and patient,[13] but these reviews did not compare the effectiveness of different synchronous and asynchronous digital health intervention tools such as SMS, smartphone applications, and website-based tools.[14–18]

To our knowledge, this systematic literature review and meta-analysis is the first to synthesise and compare the current evidence on the effectiveness and implementation of different modes of digital health interventions in adults with type 2 diabetes. Our research question was how do smartphone applications, SMS, and website-based interventions compare in terms of their reach, uptake and feasibility, and their effectiveness in reducing HbA_{1c} in people with type 2 diabetes during the past thirteen years (2009–22)?

Methods

Search strategy and selection criteria

The protocol and reporting of this systematic review and meta-analysis were consistent with the 2020 PRISMA guidelines.[19] APA PsycInfo, CINAHL Complete, Cochrane Central Register of Controlled Trials, Ovid Embase, and Ovid MEDLINE were searched on May 25, 2022, using broad search terms and MeSH terms. The search strategy was optimised to capture studies in people with type 2 diabetes and hypertension using search terms such as "type 2 diabetes", "t2d", "t2dm", "diabetic", "high blood glucose", "hypertension", "high blood pressure", and "hypertensive". The complete search strategy is in the appendix (pp 2–7). Due to the volume of data, and to allow an in-depth discussion, the findings in people with hypertension are reported in a separate manuscript.[20] In addition to the database searches, we hand-searched the reference lists of reviews of digital health interventions.

Citations and abstracts of all retrieved studies were imported into Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia). Duplicates were removed and the remaining studies were assessed for inclusion by two researchers (GS and JJ). The full list of inclusion and exclusion criteria is in the appendix (p 8). Briefly, randomised controlled trials (RCTs), cluster RCTs, pilot RCTs, crossover RCTs, and prospective RCTs of type 2 diabetes management programmes in adults, implementing digital health interventions and published in English from Jan 1, 2009, to May 25, 2022, (the date that the last searches were conducted) were considered for inclusion. Any type of digital health intervention, except for telecounselling or telemonitoring, was eligible for inclusion. Trials were excluded if the control group or groups received substantial intervention using digital tools (appendix p 8). To reflect current practice, only contemporary publications after 2009 were considered, because that was when digital health applications started to become widely adopted.[21] The systematic review protocol was registered in PROSPERO, CRD42021247845.

Data extraction

A comprehensive data extraction form was developed (GS) and refined (GS and JJ) based on the guidelines in the Cochrane Handbook for Systematic Reviews of Interventions.[22] The form was piloted on a subset of the included studies to ensure reliability and reproducibility, and then the following were extracted from all included studies (GS, JJ, and EE): publication details (title, journal, year); authors' details (names, affiliations, funding, conflict of interest); study details (start and end date, country, design, purpose, blinding and randomisation method, retention rate, statistical analyses); participants' characteristics (condition, severity of condition, comorbidities, inclusion criteria, exclusion criteria, sample size, recruitment process, and demographics [ie, age, sex, race, ethnicity, income, education, and remoteness of residence]); intervention (type, duration, frequency, other details, primary and secondary outcome factors); comparison (details of care and other details); results (timepoint for follow-up, primary and secondary outcomes [with standard deviations, standard errors of means, 95% CIs, and statistical significance], and the validated tool for measurement); and conclusions.

Evidence and outcomes

The evidence was summarised in tables including the relevant study characteristics, the intervention and comparator treatments, the purpose of the intervention, and their outcomes. The primary endpoint was the change in the mean (and 95% CI) plasma concentration of HbA_{1c} at 3 months or more. For the purposes of the evaluation of effectiveness, an intervention was classified as effective if the digital health intervention resulted in statistically significant ($p<0·05$) or clinically meaningful results (defined as a reduction in HbA_{1c} of $\geq 0·5\%$), or both,[23] as compared to the control group. The intervention was classed as not effective if there were no statistically or clinically meaningful difference, between the groups for the outcome(s). Secondary endpoints of interest included blood pressure, plasma lipid profile (ie, total cholesterol, HDL and LDL cholesterol, and triglycerides), fasting plasma glucose, changes in medication, and anthropometric outcomes (eg, BMI, bodyweight, and waist circumference).

See **Online** for appendix

Quality assessment of included studies

The revised Cochrane risk-of-bias version 2 tool was used to assess the quality of the studies on aspects of selection (random sequence generation and allocation concealment); performance and detection (masking of participants, personnel, and assessors; deviations from intended interventions; missing outcome data; and measurement of the outcome); appropriateness of analysis (selection of the reported outcome); and bias arising from period and carryover effects (for crossover studies).[24] The pertinent versions of the tool were used to appraise the quality in included RCTs, cluster RCTs, and

For more on the **Cochrane risk-of-bias version 2 tool** see https://methods.cochrane.org/bias/resources/rob-2-revised-cochrane-risk-bias-tool-randomized-trials

For the **systematic review protocol** see https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42021247845 crossover trials. Studies were ranked by three authors (GS, JJ and EE) as low risk, some concerns, or high risk. Authors resolved discrepancies by discussion.

Meta-analysis

Within-group difference in means for HbA_{1c} and their SDs for intervention and control groups were entered into Review Manager v5.4.1 software (The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen). To increase the precision of the point estimate, when only between-group and not within-group differences were reported, the latter were requested from the authors. If SE was reported instead of SD, then this was converted to SD using the formula: $SD=SE\times\sqrt{n}$. If 95% CI was reported instead of SD or SE, then the SD was calculated as described in chapter 7.7.3.2 of Cochrane's handbook.[25] Studies that did not report SD, SE, or 95% CI (and the authors of which did not respond to our request to obtain these values) were excluded from the meta-analysis. The effect sizes and SDs of the studies were pooled using the random-effects model. The random-effects meta-analysis model was selected, despite resulting in wider CIs around point estimates, because heterogeneity was expected due to the differences in study populations and procedures.[26] The robustness of the estimate was assessed via a series of sensitivity analyses that included sequentially removing each study and reanalysing the remaining datasets to identify if a single study was responsible for the direction of associations, and by testing whether the fixed-effects model would produce different results, as per the guidelines in chapter 9.7 of Cochrane's handbook.[25]

The assumption of homogeneity of true effect sizes was assessed by the Cochran's Q test, and the degree of inconsistency across studies (I^2) was calculated.[27] I^2 describes the percentage of total variation across studies that is due to heterogeneity rather than sampling error and ranges between 0% (no inconsistency) and 100% (high heterogeneity) with values of 0–40% suggesting low heterogeneity, 30–60% moderate heterogeneity, 50–90% substantial heterogeneity, and 75–100% considerable heterogeneity.[25,27] Subgroup analyses per mode of intervention were carried out to assess possible causes of heterogeneity.

Publication bias was assessed by visually inspecting a funnel plot of the mean change in HbA_{1c} plotted against the corresponding SE, on the assumption that interventions with HbA_{1c} reductions and with larger samples were more likely to be published.[25]

Quality assessment of the overall evidence

The quality of the overall evidence was assessed using Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) criteria.[28] Briefly, GRADE evaluates the type of evidence, risk of bias, consistency between studies, directness to the research question, and precision of the estimate. All 26 studies included in the meta-analysis were given an initial score of +4 for quality of evidence, because observational studies were excluded. Risk of bias was assessed as explained and in accordance with the recommendations of the Cochrane Collaboration.[22] Serious risk of bias (eg, absence of appropriate randomisation) resulted in loss of a point. Inconsistency (eg, due to substantial heterogeneity [I^2>50%]), also incurred a negative point.[29] Imprecision (eg, when the 95% CI of the pooled effect overlapped the line of no effect) also downgraded the quality of evidence total score by a point.[30] The final GRADE score was the sum of all eight categories of evidence (risk of bias, inconsistency, indirectness, imprecision, publication bias, large effect, dose response, and all plausible residual confounding). Quality of evidence was classified as high (≥4 points overall), moderate (3 points), low (2 points), or very-low quality evidence (≤1; appendix p 9).[31]

Evaluation of reach, adoption or uptake, and feasibility of interventions

We also extracted and synthesised data related to reach, adoption or uptake, and feasibility of interventions (BY-AA and VK), from those studies that reported relevant information. In line with the Medical Research Council process evaluation framework, we defined reach as the intended audience who came into contact with the intervention.[32] Feasibility was defined as the capability of carrying out an intervention or programme, and was measured in terms of acceptability, adherence, likelihood of cost-effectiveness, or capacity of providers to deliver the intervention.[33] We relied on authors' interpretations to report if the study was feasible or not based on specific aspects measured. Based on the Reach, Effectiveness, Adoption, Implementation, and Maintenance framework, adoption or uptake was defined as reported action of taking up or making use of the intervention or health promotion programme.[34,35] For this analysis, we considered reach and adoption or uptake at the individual intervention participant level. Studies using different frameworks were included, when their definitions were not considerably different from the previously mentioned.

Role of the funding source

The funder of the study had no role in the study design, data collection, data analysis, data interpretation, or writing of the manuscript.

Results

The database search yielded 3229 records and a further 13 records were identified after searching the reference lists of relevant systematic reviews. After removing 1060 duplicates, 2182 abstracts were assessed for eligibility (figure 1); 1973 abstracts were excluded along with 13 records that did not have full texts. 111 full-text articles were excluded, and reasons for exclusion are listed in the appendix (pp 10–18). After removing 29 additional studies that focused exclusively on people with hypertension (these data will be reported elsewhere[20]), 56 studies reporting the effectiveness of interventions in people with type 2 diabetes were included in the systematic review,[36–93] and 26 studies were included in the meta-analysis.

From the 56 studies, 11 486 participants from 24 regions were included (table 1). Most studies were conducted in China (n=11) and the USA (n=10; appendix p 48). All six continents were represented in this systematic review, albeit not equally, with Asia contributing 33 studies and the Americas another 13. Five studies took place in Europe, two in Africa, and three in Oceania. 28 studies were conducted in high-income economies, 17 in upper-middle-income economies, and 11 in lower-middle-income economies, according to the World Bank classification.[94] 41 studies were conducted from 2016 and after, and 15 between 2009 and 2015. All studies were RCTs, with 45 employing a parallel group design, two being cluster, three pilot, and six prospective (appendix pp 49–50). 20 studies used SMS as the primary mode of delivery of the digital health intervention,[36–55] 25 used smartphone applications,[56–82] and 11 used websites.[83–93]

Interventions varied to align with the purpose of each study (appendix pp 19–47). SMS interventions delivered educational messages to increase participants' literacy on aspects of their condition and the importance of lifestyle modifications such as physical activity and diet, promote medication adherence, provide reminders for regular self-monitoring of blood glucose levels or blood pressure, and increase medication adherence and adjustment (eg, titration of insulin doses).[44] Behaviour change models (eg, the transtheoretical model) were employed to promote motivation.[45] Studies that included immigrants adjusted SMS to the language of participants.[38] Other studies personalised content to the demographics of participants (eg, education status[39] and ethnicity).[40] SMS frequency ranged from daily to weekly.

Smartphone applications were also used for education,[56] but due to the capabilities of modern smartphones, applications included additional features that enabled telemonitoring and communication between participants and health-care professionals as well as participant group chats. Some studies offered free-of-charge feedback ad libitum via the application.[56] Several application interventions required participants to regularly self-monitor their blood glucose levels or blood pressure, and to log these values, along with their food intake, physical activity, and medication, allowing health-care professionals to provide real-time advice for medication adjustment and tips for lifestyle modifications. To allow this real-time monitoring and advice, most application interventions included one or more telemonitoring devices such as external or inbuilt accelerometers, but also ingestible sensors, and adhesive wearable sensor patches.[62] Bluetooth technology was also used for communication between different wearable sensors and the application.[63]

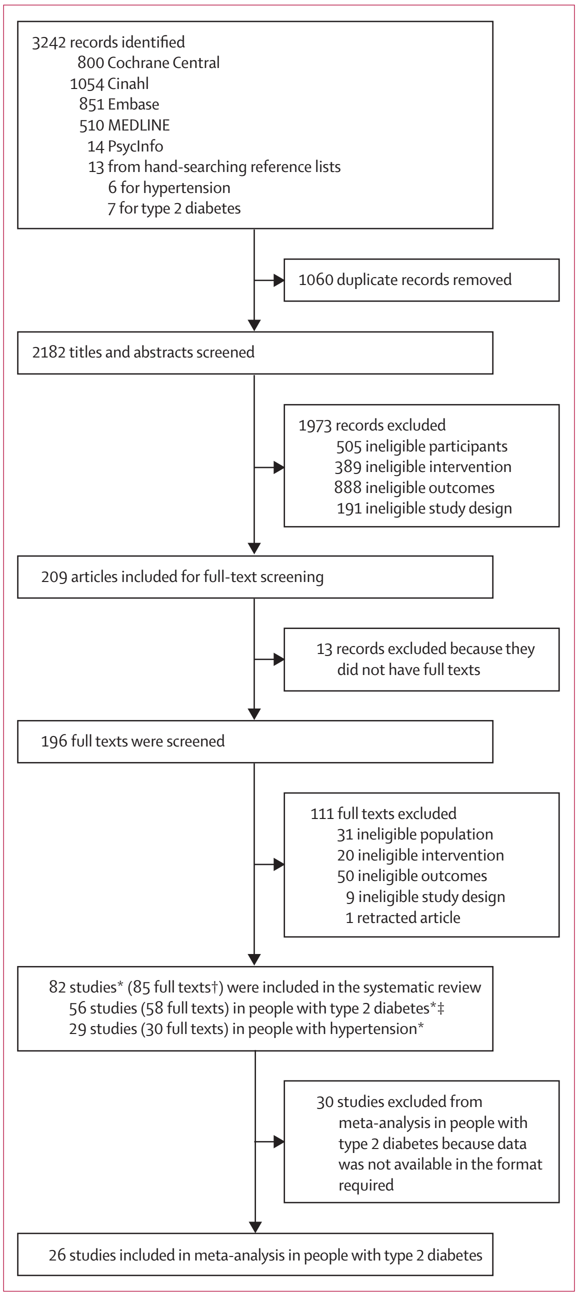

Figure 1: **Study selection**
*Three studies included participants with type 2 diabetes and hypertension. †Three studies' results were reported in two manuscripts. ‡The included studies in people with hypertension are reported in a separate manuscript.[20]

A few studies assessed the effect of applications alone, compared with application plus telemonitoring, on relevant clinical parameters.[61] Other applications included sending alerts to physicians, with atypical readings triggering prompt intervention.[76] Teleconsultations were facilitated by inbuilt features such as voice, video, picture, or SMS.[77] Effective interventions that used diet logs incorporated culturally adjusted food databases that

	Study design; duration; number of participants; retention	Intervention	Outcomes	
			Primary	Secondary
Characteristics of included studies that incorporated SMS interventions				
Abaza et al (2017),[36] Egypt	RCT; 12 weeks; 90; 81%	Daily SMS on diet, physical activity, complications, reminder prompts to test and record; 12 SMS from each category (84 in total); booklet of diabetes care instructions	ΔHbA_{1c} –1·679% (intervention) and –1·389% (control; p=0·406)	ΔBGL –19 mg/dL (control) and –61 mg/dL (intervention; p=0·288); Δbodyweight –0·5 kg (control) and –1·3 kg (intervention; p=0·215)
Argay et al (2015),[37] Hungary	Prospective RCT; 12 months; 131; 94%	Medication reminders three times per day; SMS could be customised	ΔHbA_{1c} –0·06% (intervention) and –0·4% (control; p=0·212)	None
Arora et al (2014),[38] USA	RCT; 6 months; 218; 72%	Daily SMS in English or Spanish with educational and motivational content, medication reminders, and healthy living challenges	ΔHbA_{1c} –1·05% (intervention) and –0·6% (control; p=0·230)	Medication adherence of Δ=1·1 (95% CI 0·1 to 2·1); percentage using emergency services 35·9% (intervention) and 51·6% (control); percentage who used primary care 56·3% (intervention) and 53·1% (control)
Capozza et al (2015),[39] USA	RCT; 180 days; 93; 60%	Daily diabetes-related SMS written at fifth-grade reading level; weekly reminders to monitor blood pressure; web-based portal with stored responses	No statistically significant ΔHbA_{1c} between intervention and control (p>0·05)	Mean total satisfaction score of 27·77 (SD 3·85); patients identified as Spanish had difficulty with patient interaction
Dobson et al (2020),[40] New Zealand	RCT; 9 months; 366; 80%	Two unidirectional SMS per week automated for motivation, diabetes education, and lifestyle; messages were personalised by demographic factors (Māori and non–Māori), personal goals, and preferences	ΔHbA_{1c} –0·9% (intervention) and –0·1% (control; p<0·0001)	None
Fang et al (2018),[41] China	RCT; 12 months; 129; 84%	Appointment reminders and health information (prepared by a nurse or a doctor) sent by microletter and SMS; topics on T2D, CVD risk factors, diabetes complications and risks, frequency of blood glucose self-monitoring, reducing carbohydrate consumption, significance of BMI, and need for regular physical activity	ΔHbA_{1c} –0·41% (intervention) and 0·09% (control; p=0·034)	FPG (p=0·007), postprandial plasma glucose (p<0·001), fasting insulin (p=0·004), postprandial insulin (p<0·001), total cholesterol (p<0·001) and LDL (p<0·001) decreased significantly in intervention group but SBP decreased significantly in the control group only (p=0·014)
Fortmann et al (2017),[42] USA	RCT; 6 months; 126; 90%	Daily culturally adapted educational and motivational SMS with medication reminders, BGL monitoring prompts; study coordinator contacted anyone who did not send BGL for 1 week	ΔHbA_{1c} –1% (intervention) and 0·2% (control; p=0·03)	96% reported intervention helped management a lot; 97% would recommend the intervention to friend or family member with T2D
Goodarzi et al (2012),[43] Iran	RCT; 3 months; 81; 81%	Four SMS per week on diet, physical activity, medication, and self-monitoring of BGL	ΔHbA_{1c} –0·89% (intervention) and –0·35% (control; p=0·024)	Intervention compared with control, significantly improved LDL (p=0·019), cholesterol (p=0·002), blood urea nitrogen (p≤0·001), micro albumin (p≤0·001), knowledge (p≤0·001), practice (p≤0·001), and self-efficacy (p≤0·001)
Shariful Islam et al (2015),[48] Bangladesh	Prospective RCT; 6 months; 236; 85%	Daily SMS based on the principles of behavioural learning theory; an SMS delivery manager website was created, and SMS were delivered in partnership with Grameenphone Bangladesh	ΔHbA_{1c} –0·85% (intervention) and –0·18% (control; p<0·0001)	Medication adherence decreased significantly in both groups with no significant difference between groups
Kim et al (2010),[44] South Korea	RCT; 12 weeks; 100; 92%	Internet-based diabetes patient management system using daily SMS that produces automatic adjustment of insulin dose based on BGL; orientation on insulin, physical activity, dietary advice from an endocrinologist, nurse, dietitian, and pharmacist	ΔHbA_{1c} –2·4% (intervention) and –2·0% (control; p=0·023); percentage with HbA_{1c} <7% was 25·5·% (intervention) and 15·6% (control; p=0·235)	Δbodyweight +2·4 kg (intervention) and +2·2 kg (control; p=0·653); no change between groups in incidence of hypoglycaemia; FBG and postprandial BGL declined earlier in the intervention *vs* control group
Lim et al (2011),[45] South Korea	RCT; 6 months; 103; 94%	Medical instructions given via mobile phone; glucometer that automatically transfers results to hospital–based server, then system sends automatic patient-specific SMS	ΔHbA_{1c} –0·4% (intervention) and 0·1% (control; p=0·274)	Percentage with HbA_{1c} <7% without hypoglycaemia 30·6% (intervention) and 14·0% (control; p<0·05)
Peimani et al (2016),[49] Bahrain	RCT; 3 months; 250; 100%	Tailored SMS group and non-tailored SMS group; the tailored group received 75% of messages tailored to top two barriers reported in survey or scale; the non-tailored group received random messages regardless of barriers; SMS provided education on diet, physical activity, BGL monitoring and medication adherence	ΔHbA_{1c} –0·23% (tailored SMS), –0·27% (non–tailored SMS), and 0·03% (control; p=0·19)	Mean Self–Care Inventory scores significantly increased and mean Diabetes Self–Care Barriers and Diabetes Management Self–Efficacy Scale scores significantly decreased in both tailored and non–tailored SMS groups
Ramallo–Fariña et al (2020),[46] Spain*	Cluster RCT; 24 months; 2334; 72%	Eight educational sessions (one every 3 months); monitoring of physical activity, diet, drug adherence, mood, BP, and BGL; weekly access to a website and tailored feedback by semi-automated SMS based on results from website, focusing on education and behaviour modification	ΔHbA_{1c} at month 6 –0·26 (95% CI 0·44 to 0·08) in favour of intervention	None
Sadanshiv et al (2020),[47] India	RCT; 3 months; 320; 95%	Automatic SMS based on transtheoretical model of behavioural change with educational content regarding healthy eating habits and physical activity; two messages per week for 3 months	ΔHbA_{1c} –0·48 in favour of intervention (p<0·001)	ΔBMI –0·6 in favour of intervention (p<0·001); 96% of intervention group received regular messages, of which 93% read the messages and 80% acted on them; 93% felt satisfied with their health care

(Table 1 continues on next page)

	Study design; duration; number of participants; retention	Intervention	Outcomes	
			Primary	Secondary
(Continued from previous page)				
Shetty et al (2011),[50] India	Pilot RCT; 12 months; 215; 67%	One SMS every 3 days on principles of diabetes management (eg, diet, physical activity, medication reminders, and lifestyle); SMS contents and frequencies varied as per the patients' preferences	No significant difference in HbA_{1c} decrease between groups	FPG (p<0·002) and 2 h PG (p<0·002) decreased significantly in the SMS group
Tamban et al (2014),[51] Philippines	RCT; 6 months; 104; 79%	Three SMS per week in Filipino (Mondays was about diet, Wednesdays was about exercise, and Fridays was about consequences of not adhering to diabetes management); SMS was evaluated by endocrinologist and a diabetes educator after which a focus group discussion was facilitated by the primary investigator among ten diabetes patients to determine if the SMS could be easily understood	ΔHbA_{1c} –0·47% (intervention) and –33% (control; p=0·034)	Significant difference in favour of intervention for mean number of meals per day (p=0·018) and mean number of minutes per exercise (p=0·021)
Vinitha et al (2019),[52] India	RCT; 24 months; 248; 88%	Educatory SMS (2–3 times a week) on healthy lifestyle practices and adherence to medication; tailored advice on diet and physical activity	ΔHbA_{1c} 2·1% (intervention) and –1·7% (control; p=0·044)	ΔFPG and ΔBP, significantly lower (p=0·007) in intervention *vs* control group; significant reduction in total calorie and fat intake in both groups
Wargny et al (2018),[53] Senegal	Crossover RCT; 3 months; 186; 97%	Two centres (S and P) served as intervention and control by time randomisation; intervention received daily SMS during the first three months then no SMS; same SMS series (50 SMS overall) were sent to each intervention group	ΔHbA_{1c} month 0 to 3 –0·4% (intervention [S]) and +0·2% (control [P]; p=0·0038); ΔHbA_{1c} month 3 to 6 –0·2% (control [S]) and +0·1% (intervention [P])	Campaign cost US$3·1 per person
Whittemore et al (2020),[54] Mexico	Pilot RCT; 6 months; 85; 94%	Seven interactive group–based educational sessions (tailored socioculturally); daily text or picture messages to promote behaviour change; education on physical activity, stress management, medication adherence, prevention of complications, and on nutrition (based on the smart plate)	ΔHbA_{1c} –1·77% (intervention) and –0·96% (control; p=0·11)	Group-by-time effects seen in SMBG and diabetes self-efficacy; time effects for intervention group including improved self-care behaviour (diet, physical activity, SMBG), self-efficacy and depressive symptoms; time effects for control group including improved physical activity, SMBG, and depressive symptoms
Xu et al (2020),[55] USA	RCT; 6 months; 65; 57%	Two to three SMS per week; self-reporting of FPG by responding to automated telephone calls or SMS; high FPG triggered automated alert via text or telephone call to the provider for possible acute event, and the platform issued an automated instruction directly to patients to contact their providers or call 911, or both; messages written at fourth grade level	ΔHbA_{1c} –0·69% (intervention) and –0·03% (control; p=0·055)	ΔFPG –21·6 mg/dL (intervention) and +13·0 mg/dL (control; p=0·946); response rate 63·6% (intervention) and 64·9% (control); engagement rate 58% (intervention) and 48% (control)
Characteristics of included studies that incorporated smartphone app interventions				
Omar et al (2020),[56] United Arab Emirates	RCT; 6 months; 218; 75%	Structured education via WhatsApp as per the American Association of Diabetes Educators Self-Care Behaviours recommendations; daily messages contained information about healthy eating, food portions, physical activity, self-monitoring of BGL, reminders for medication intake, and insulin use; participants could seek advice and get free-of-charge feedback via the app	ΔHbA_{1c} –0·7% (intervention) and –0·1% (control; clinically significant)	Patient satisfaction: 90% of patients reported preference to continue social media intervention, 80% said it was beneficial, and 67% found it convenient
Anzaldo-Campos et al (2016),[57] Mexico	RCT; 10 months; 202; 90%	Interactive surveys; SMS, short educational videos through a mobile phone app; the interactive survey was designed to promote tracking and accountability; participants received a MyGlucoHealth glucose meter, glucose test strips, and a 3G-enabled mobile phone	ΔHbA_{1c} –3·0% (intervention) and –1·3% (control; p=0·009)	Intervention significantly improved diabetes knowledge compared with control (p 0·05)
Bender et al (2017),[58] USA	Pilot crossover RCT; 3 months; 45; 100%	Accelerometer to self-monitor physical activity real time (steps); associated app with diary to self-report daily food intake and weekly weight; study's private Facebook group for virtual support, coaching, and weekly education topics posted by research staff	Opposing and mixed patterns were displayed in the HbA_{1c} outcomes	Attendance at all seven intervention office visits was 95% (intervention) and 100% (control); in both phases, group receiving intervention displayed improved values for step counts, bodyweight, BMI and, waist circumference
Chao et al (2019),[59] China	RCT; 18 months; 121; 98%	Mobile app to facilitate pre-intervention and post-intervention assessments and behaviour changes	Intervention improved ΔHbA_{1c} significantly (p=0·02) more than control (no values reported)	86% of participants improved health knowledge through mobile app
Dong et al (2018),[60] China	RCT; 12 months; 121; 98%	Health education via WeChat; bidirectional	ΔHbA_{1c} –2·92% (intervention) and –0·88% (control; p<0·05)	No significant difference of FPG and 2 h PG concentrations were found between intervention and control (p>0·05)
Franc et al (2020),[61] France	RCT; 12 months; 434; 100%	Intervention groups: app only; app and telemonitoring; smartphone app that incorporates patient data and calculates insulin dose; data are sent every 2 h to a platform which is monitored by nurse and the investigator; automatic messages containing analytical data produced daily	ΔHbA_{1c} –0·20% (control) –0·34% (app only), and –0·26% (app and telemonitoring; comparable between arms)	Post-hoc analysis in participants using the app ≥1 times per day showed significant reduction (app only *vs* control, p=0·001; app and telemonitoring *vs* control p≤0·001); no significant differences between groups for symptomatic hypoglycaemia (p=0·129)

(Table 1 continues on next page)

	Study design; duration; number of participants; retention	Intervention	Outcomes	
			Primary	Secondary
(Continued from previous page)				
Frias et al (2017),[62] USA	Prospective pilot cluster RCT; 12 weeks; 109 with both T2D and HTN; 91%	Smartphone app; ingestible sensor-adhesive wearable sensor patch; provider web portal; feedback for medication taking and other health behaviours to both patients and providers	ΔHbA_{1c} –0·19 (intervention) and +0·26% (control); $\Delta HbA_{1c\,intervention-control}$ –0·48% (95% CI –1·04 to –0·09%)	ΔSBP –21·8mm Hg (intervention) and –12·7 mm Hg (control); $\Delta SBP_{intervention-control}$ –9·1 mm Hg (95% CI –14·5 to –3·3); percentage of participants that achieved BP goal was 80·0% (intervention) and 51·7% (control); difference=28·3%
Gong et al (2020),[63] Australia	RCT; 12 months; 187; 87%	Smartphone app for personalised support, monitoring, and motivational coaching via a conversational agent; access to website; blood glucose meter with Bluetooth; brief, structured interactions with a programme coordinator	ΔHbA_{1c} –0·33% (intervention) and –0·28% (control; p=0·03)	None
Gunawardena et al (2019),[64] Sri Lanka	RCT; 6 months; 67; 78%	Android-based Smart Glucose Manager app that provides medication and BGL monitoring reminders, and prompts for healthy eating and physical activity	ΔHbA_{1c} –2·32% (intervention) and –1·27% (control; p<0·0001)	None
Hilmarsdóttir et al (2021),[65] Iceland	RCT; 6 months; 37; 81%	Smartphone app with digital lifestyle programme (gamified technology) to enhance lifestyle change; healthy behaviours are rewarded health points that mount up and result in water donations to UNICEF as an extra reward	ΔHbA_{1c} –0·7% (intervention) and –0·1% (control; p=0·190)	None
Kleinman et al (2016)[66] and Kleinman et al (2017),[67] India	RCT; 6 months; 91; 89%	Smartphone app and web portal for T2D management, informed by theories of behaviour change; provided reminders, data visualisation, and ongoing support to increase self-care behaviours and assist collaborative care decisions	ΔHbA_{1c} –1·5% (intervention) and –0·8% (control; p=0·02)	Medication adherence was 39·0% (intervention) and 12·8% (control; p=0·03); frequency of BGL self-testing was 39·0% (intervention) and 10·3% (control; p=0·01); 80% were satisfied with app
Ku et al (2020),[68] South Korea	Pilot RCT; 12 weeks; 40; 88%	Smartphone app for weight control and dietary management; logging diet to calculate dietary intake using a database of local foods; >3·7 million food options and 50 000 Korean food items, updated by registered nutritionist; colour coding (red, yellow, and green) to help healthier food choice; pedometer	% achieving target HbA_{1c} 47·1% (intervention) and 11·1% (control; p=0·019)	Summary of Diabetes Self-Care Activities questionnaire showed improvement in both groups (except for exercise) with no difference between groups other than foot care (p=0·008)
Kumar et al (2021),[69] India	RCT; 6 months; 300; 100%	Smartphone app focusing on lifestyle modification and medication management; app also answered frequently asked questions and provided tips and references	ΔHbA_{1c} – 0·26% (intervention) and +0·13% (control; p=0·01)	None
Lee et al (2020),[70] South Korea	RCT; 6 months; 140; 92%	Smartphone app and individualised feedback messages from health-care professionals for diabetes self-management education; medical information was entered to the mobile app and shared through social network services	ΔHbA_{1c} 0·1% (control) and –0·3% (intervention; p=0·05)	None
Li et al (2021),[71] China	Prospective RCT; 6 months; 101; 84%	Smartphone app to display exercise videos; wearable chest band to monitor heart rate, exercise duration and intensity	ΔHbA_{1c} –0·55% (intervention) and –0·70% (control; p>0·05)	Change in body fat percentage was –1·8% (intervention) and –0·8% (control; p=0·01)
Lu et al (2021),[72] China	RCT; 6 months; 120; 99%	WeChat for medication alarm clock, medication guidance, and automatic drug instruction query; in–hospital pharmacy consultation and medication evaluation, and drug reorganisation with medical monitoring and advice	ΔHbA_{1c} –1·77% (intervention) and –1·03% (control; p=0·002)	ΔFBG was –1·68 mmol/L (intervention) and 1·01 mmol/L (control; p=0·077)
Or et al (2020),[73] Hong Kong	RCT; 24 weeks; 299 with both T2D and HTN; 97%	Smartphone app to record BP and blood glucose via Bluetooth-connected monitors; data accessible by health professionals via web portal; education for the prevention of T2D and HTN, self-care, diet, exercise, health plans, and stress management	ΔHbA_{1c} –0·45% (intervention) and –0·35% (control; p=0·52)	ΔSBP was +0·5 mm Hg (intervention) and –2·8 mm Hg (control; p=0·10); ΔDBP –0·1 mm Hg (intervention) and –0·5 mm Hg (control; p=0·73)
Quinn et al (2016),[74] USA	Cluster RCT; 12 months; 118; retention not reported	Smartphone app for patient coaching and provider clinical decision support; patients entered diabetes self-care data on a mobile phone and receive automated, real-time messages	Aged ≥55 years group ΔHbA_{1c} –1·8% (intervention) and –0·3% (control; p=0·001); aged <55 years group ΔHbA_{1c} –2·0% (intervention) and –1·0% (control; p=0·02); no significant difference between two age groups (p=0·44)	None
Sun et al (2019),[75] China	RCT; 6 months; 91; retention not reported	App–based diet management software to input daily dietary intake; dietitian analysed this dietary record and provided once-monthly dietary recommendations; physical activity information (daily calorie expenditure) was obtained from participants in intervention group via text message, followed by guidance related to aerobic and resistance-based exercises; participants given glucometers capable of data transmission	ΔHbA_{1c} –0·87% (intervention) and –0·70% (control; p=0·25)	None

(Table 1 continues on next page)

	Study design; duration; number of participants; retention	Intervention	Outcomes	
			Primary	Secondary
(Continued from previous page)				
Waki K et al (2014),[76] Japan	RCT; 12 weeks; 54; 100%	Smartphone app for self-management diabetes control; app monitors health data including BGL, BP, bodyweight, and step counts; atypical readings trigger intervention by physician; participants can record physical activity and diet and receive feedback	ΔHbA_{1c} −0·4% (intervention) and +0·1% (control; p=0·015)	Change in fasting blood sugar −5·5 mg/dL (intervention) and +16·9 mg/dL (control; p=0·019)
Wang et al (2019),[77] China	RCT; 6 months; 120; 100%	Smartphone app for health monitoring (BGL, diet, insulin and related drug use, and physical activity) followed by relevant physician recommendation; voice, picture, video, or text messages to facilitate teleconsultations	ΔHbA_{1c} −1·50% (intervention) and −0·76% (control; p<0·05)	ΔFBG −3·23 mmol/L (intervention) and −1·25 mmol/L (control; p<0·05); Δ in postprandial BGL −4·34 mmol (intervention) and −2·34mmol (control; p<0·05); disease awareness levels 1·28 (intervention) and 71·34 (control; p<0·05); self-management abilities 9·14 (intervention) and 7·81 (control; p<0·05)
Yu et al (2019),[78] China	RCT; 24 weeks; 185; 87%	Intervention groups were SMBG (B), app only (C), and app and SMBG (D); smartphone app for diabetes education, self–management, patient community, and real–time communication between patients and clinicians; SMBG group received blood glucose meter and strips	ΔHbA_{1c} −1·1% (control), −1·1% (B), −1·1% (C), and −1·1% (D; p>0·005)	Percentage that achieved HbA_{1c} <7%: 25·5% (A), 44·4% (B), 60·4% (C), and 62·2% (D)
Yun et al (2020),[79] South Korea	RCT; 12 weeks; 106 with both T2D and HTN; 76%	Smartphone app for patient self-assessment, self-planning, self-learning, and self-monitoring by automatic feedback; patients created own health management weekly plan and monitored their progress on vegetable and fruit intake, physical activity, and medication	ΔHbA_{1c} −0·71% (intervention) and −0·22% (control; p=0·014)	ΔSBP in patients with HTN −17·5 mm Hg (intervention) and −11·6mm Hg (p=0·41); % that met target clinical indicators for HTN was 72·7% (intervention) and 35·7% (control; p=0·035); ΔLDL (patients with high LDL) was −23·7 mg/dL (intervention) and −25·3 mg/dL (control; p=0·72)
Zhang et al (2019)[80] and Zhang et al (2019),[81] China	Prospective RCT; 6 months; 234; 83%	Intervention groups were self-management with smartphone app for diabetes-related knowledge and skills, including glycaemic control, diet, exercise, medication, and the use of insulin (A); and as in A plus online interactive management with a dietitian and a health manager (A+)	ΔHbA_{1c} −2·03% (control), −1·37% (A), and −2·03% (A+; A+ *vs* control p=0·01; A+ *vs* A p=0·01); ΔFPG 8·91(control), 9·08 (A), and 7·87 (A+; A+ *vs* control p=0·02; A+ *vs* A p<0·01)	ΔHDL 1·20 (control), 1·16 (A), and 1·20 (A+; all p<0·05)
Zhou et al (2016),[82] China	RCT; 3 months; 100; 100%	Smartphone app that stores self-care data (BGL, carbohydrate intake, medications, and other diabetes management information) for diabetes management	ΔHbA_{1c} −1·95% (intervention) and −0·79% (control; p<0·001)	ΔFBG −1·89 mmol/L (intervention) and −0·95 mmol/L (control; p<0·05); SBP −2·0 mm Hg (intervention) and −0·6 mm Hg control; (p>0·05)
Characteristics of included studies that incorporated website-based interventions				
Hansel et al (2017),[83] France	RCT; 16 weeks; 120; 89%	Online dietetic tool for personalised menus and daily or weekly shopping list; human contact limited to hotline support in cases of technical issues; prescription of physical activity	ΔHba_{1c} −0·37% (intervention) and +0·23% (control; p<0·001)	Change in dietary score +4·55 (intervention) and −1·68 (control; p=0·28); Δbodyweight−2·9 kg (intervention) and +0·2 kg (control: p<0·01)
Heisler et al (2019),[84] USA	RCT; 6 months; 290; 82%	Tailored, interactive web-based tool for diabetes education, assessment of barriers to treatment adherence, and goal setting and coaching; peer mentors followed up with weekly computer-facilitated calls	ΔHba_{1c} at 6 months −0·70% (intervention) and −0·68% (control; not significant); ΔHba_{1c} at 12 months −0·56% (intervention) and −0·52% (control; not significant)	No significant changes in BP
Jaipakdee et al (2015),[85] Thailand	RCT; 6 months; 403; 94%	Computer-assisted instruction for diabetes education and lifestyle change; nurses helped participants define goals and develop action plan	ΔHba_{1c} −0·4% (intervention) and −0·3% (control; p=0·334); FPG −16·2 mg/dL (intervention) and −0·7 mg/dL (control; p=0·001)	Bodyweight −1·9 kg (intervention) and 0·5 kg (control; p=0·001); QoL 5·7 (intervention) and 2·3 (control; p<0·001)
Kim et al (2016),[86] China	RCT; 6 months; 220; 83%	Internet blood glucose monitoring system; participants uploaded BGL for monitoring by medical staff and received weekly recommendations regarding BGL control	ΔHbA_{1c} −1·2% (intervention) and −0·6% (control; p<0·001); postprandial BGL −0·9mmol/L (control) and −0·9mmol/L (intervention; p<0·001)	ΔHDL +0·1 mmol/L (control) and 0·0 mmol/L (intervention; p<0·001); change in SBP, DBP, BMI, total cholesterol, LDL, and triglyderides not significant
Leichter et al (2013),[87] China	RCT; 3 months; 101; 84%	Data management software with blood glucose meter; office visits at 6 and 12 months; visits via the internet and telephone at 3 and 9 months	ΔHbA_{1c} at 12 months −0·55% (intervention) and −0·70% (control; p>0·05)	ΔBMI at 12 months: −0·60 kg/m^2 (intervention) and −0·32 kg/m^2 (control; p=0·09)
McLeod et al (2020),[88] New Zealand	RCT; 12 months; 429 with prediabetes or T2D; 96%	Programme delivered through mobile devices and web-based platforms, which included individual health coaching, fortnightly provision of evidence-based resources, online peer support through a closed forum, and online goal tracking	ΔHbA_{1c} in patients with T2D 0·0% (intervention) and 0·0% (control; p=0·366)	ΔBMI: −0·4 kg/m^2 (intervention) and −0·2 kg/m^2 (control; p=0·464)

(Table 1 continues on next page)

	Study design; duration; number of participants; retention	Intervention	Outcomes	
			Primary	Secondary
(Continued from previous page)				
Pacaud et al (2012),[89] Canada	RCT; 12 months; 79; 86%	Intervention groups were Web Static intervention that received electronic education and virtual appointments using asynchronous communication (emails) and Web Interactive that received the same information via both synchronous and asynchronous communication	ΔHbA_{1c} –0·37% (web interactive female), –1·58% (web interactive male), +0·07% (web static female), –0·44% (web static male), –0·65% (control female), and +0·06% (control male; significant differences for males but not for females)	None
Ralston et al (2009),[90] USA	RCT; 12 months; 83; 89%	Web-based programme for patient access to electronic medical records, secure email with providers, feedback on BGL, educational website, and interactive online diary logging information on physical activity, diet, and medication	ΔHbA_{1c} –0·9% (intervention) and +0·2% (control; p<0·01)	BP, total cholesterol, and use of in-person health-care services did not differ between the two groups
Ramadas et al (2018),[91] Malaysia	RCT; 12 months; 132; 86%	e-intervention to deliver lessons based on the recommendations, objectives and dietary stages of change	ΔHbA_{1c} –0·6% (intervention) and –0·5% (control; p=0·511)	Dietary knowledge and attitude behaviour: F statistic=244·212 (intervention) and F statistic=62·453 (control; p<0·001)
Tang et al (2013),[92] USA	RCT; 12 months; 415; 91%	Wireless glucometer; diabetes summary status report regarding personalised action plan, goals, diabetes complications risk, monitoring tests, medications, and health maintenance schedule; diet and physical activity log; insulin record; online communication with health-care team; tailored text and video educational nuggets	ΔHbA_{1c} at 6 months –1·32% (intervention) and –0·66% (control; p<0·001); ΔHbA_{1c} at 12 months –1·14% (intervention) and –0·95% (control; p=0·132); LDL at 12 months 0·0 mg/dL (control) and –6·1 mg/dL (intervention; p=0·001)	Framingham risk –0·5% (control) and –0·6% (intervention; p=0·051); SBP, DBP, and bodyweight did not differ significantly between groups
Zhou et al (2014),[93] China	Prospective RCT; 3 months; 114; 95%	Web-based system as main intervention but professional staff also contacted participants via SMS, online communication, and telephone	ΔHbA_{1c} –95% (intervention) and –0·79% (control; p<0·001)	ΔFBG 1·89 mmol/L (intervention) and –0·95 mmol/L (control; p<0·005); no significant change in BMI and BP between groups

2 h PG=2 hour postprandial plasma glucose. app=application. BGL=blood glucose level. BP=blood pressure. CVD=cardiovascular disease. DBP=diastolic blood pressure. FPG=fasting plasma glucose. HbA_{1c}=glycated haemoglobin A_{1c}. HTN=hypertension. LDL=low-density lipoprotein. QoL=quality of life. RCT=randomised control trial. SBP=systolic blood pressure. SMBG=self-monitoring of blood glucose. T2D=type 2 diabetes. *Reported values are approximations of combined reported values for different subgroups within the study. A full version of the study characteristics including details on participant baseline characteristics, the control group, and the purpose of the study can be found in the appendix (pp 19–47).

Table 1: **Characteristics of included studies that incorporated SMS, smartphone application, and website-based interventions**

included local food item options.[68] Gamified technology was used to instil behaviour changes but this was not as successful.[65] Website-based interventions comprised educational web pages,[84] social network support groups,[58] online counselling,[91] and telemonitoring.[86]

Most studies compared interventions to usual care or an enhanced version of usual care (eg, some form of education).[85] In most studies, education for the control group occurred only at baseline;[52] however, there were a few studies that offered participants education throughout their duration. A few studies offered very limited access to the digital health intervention for control participants, mostly at baseline.[55]

Overall, the methodological quality varied markedly with 26 (46%) studies classified as high risk of bias, six (11%) studies as moderate risk of bias, and 24 (43%) studies as low risk of bias (appendix p 51). 12 studies were assessed as high risk of bias for not masking participants and study personnel to intervention assignment or maintaining similar baseline characteristics;[38–40,42,44–47,58,63,66,87] however, such masking or even distribution of characteristics is typically not possible in digital interventions that target behaviour change. Eight studies did not provide complete information about the randomisation or the concealment process.[39,46,59,62,76,82,89,90] Regarding deviations from intended intervention, one study reported adjustments in study timeline were necessary due to Ramadan;[36] and four studies did not report on the masking of participants.[43,46,53,60] Regarding attrition bias, 13 studies reported high attrition rates or inadequate method to eliminate potential bias caused by missing data, or both.[42,43,46,50,51,55,57,66,67,79,80,84,87] Regarding measurement bias, ten studies employed self-reporting of outcomes or did not provide information on adequate training of personnel for the measurement of outcomes.[36,39,43,47,51,55,57,66,75,77]

Out of the 56 RCTs, trials that recruited participants with higher baseline values for HbA_{1c} reported the greatest effectiveness in terms of improving HbA_{1c}.[39,44,53,58,66–68,85,87] Pacaud and colleagues[89] reported a significant reduction in HbA_{1c} in males only, but male participants had a higher baseline HbA_{1c} than females. A dose response was seen when participants used the application more than once per day.[61] Education level was positively associated with intervention effectiveness.[62,63,68,74,80] 34 studies reported clinically meaningful reductions in HbA_{1c} (≥0·5%) for their digital health intervention group,[38,40,42–45,48,51–57,59,60,64,65,67,68,71,72,74,75,77–80,82,84,90–93] compared with 24 that reported clinically meaningful reductions for their control group.[38,44,51,52,54,57,59,60,64,67,68,71,72,74,75,77,78,80,82,84,91–93]

	Intervention			Control			Weight	Mean difference inverse variance, random (95% CI)
	Mean	SD	Total	Mean	SD	Total		
SMS								
Argay et al (2015)[37]	−0·06	0·84	65	−0·40	1·11	66	4·1%	0·34 (0·00 to 0·68)
Arora et al (2014)[38]	−1·05	0·52	64	−0·60	0·59	64	5·5%	−0·45 (−0·64 to −0·26)
Dobson et al (2020)[40]	−0·90	1·80	177	−0·10	1·80	116	3·4%	−0·80 (−1·22 to −0·38)
Fang et al (2018)[41]	−0·41	1·21	58	0·09	1·24	51	3·1%	−0·50 (−0·96 to −0·04)
Shariful Islam et al (2015)[48]	−0·86	1·08	106	−0·18	1·53	94	3·8%	−0·68 (−1·05 to −0·31)
Ramallo-Fariña et al (2020)[46]	−0·20	0·21	537	0·03	0·22	586	6·5%	−0·23 (−0·26 to −0·20)
Sadanshiv et al (2020)[47]	−0·06	0·96	159	−0·06	0·96	159	5·3%	0·00 (−0·21 to 0·21)
Whittemore et al (2020)[54]	−1·77	1·73	26	−0·96	1·70	21	1·1%	−0·81 (−1·80 to 0·18)
Xu et al (2020)[55]	−0·70	0·33	33	−0·03	0·43	32	5·5%	−0·67 (−0·86 to −0·48)
Subtotal (95% CI)			**1225**			**1189**	**38·4%**	**−0·37 (−0·57 to −0·17)**
Heterogeneity: τ^2=0·06; χ^2=56·58, df=8 (p<0·0001); I^2=86%								
Test for overall effect: Z=3·68 (p=0·0002)								
Smartphone application								
Omar et al (2020)[56]	−0·70	0·84	84	−0·10	0·58	80	5·2%	−0·60 (−0·82 to −0·38)
Anzaldo-Campos et al (2016)[57]	−3·02	2·83	102	−1·30	3·29	100	1·4%	−1·72 (−2·57 to −0·87)
Frias et al (2017)[62]	0·26	0·35	32	−0·19	0·14	39	6·0%	0·45 (0·32 to 0·58)
Gong et al (2020)[63]	−0·33	0·26	79	−0·28	0·26	83	6·3%	−0·05 (−0·13 to 0·03)
Kleinman et al (2017)[67]	−1·50	1·10	44	−0·80	1·60	47	2·5%	−0·70 (−1·26 to −0·14)
Ku et al (2020)[68]	−1·90	1·60	17	−1·00	1·00	18	1·3%	−0·90 (−1·79 to −0·01)
Kumar et al (2021)[69]	−0·20	0·21	150	0·1 0	0·21	150	6·5%	−0·30 (−0·35 to −0·25)
Li et al (2021)[71]	−0·55	2·47	44	−0·70	2·94	41	0·8%	0·15 (−1·01 to 1·31)
Quinn et al (2016);[74] >55 years	−2·00	1·80	37	−1·11	2·20	29	1·1%	−0·89 (−1·88 to 0·1)
Quinn et al (2016);[74] ≤55 years	−1·70	2·00	25	−0·30	1·40	27	1·2%	−1·40 (−2·35 to −0·45)
Sun et al (2019)[75]	−1·07	0·89	44	−0·62	1·00	47	3·7%	−0·45 (−0·84 to −0·06)
Waki K et al (2014)[76]	−0·4	0·80	7	0·10	0·70	15	1·9%	−0·50 (−1·19 to 0·19)
Yu et al (2019)[78]	−1·10	0·30	48	−1·10	0·40	47	5·9%	0·00 (−0·14 to 0·14)
Zhou et al (2016)[82]	−1·95	1·70	50	−0·79	1·10	50	2·5%	−1·16 (−1·72 to −0·60)
Subtotal (95% CI)			**763**			**773**	**46·2%**	**−0·42 (−0·63 to −0·20)**
Heterogeneity: τ^2=0·10; χ^2=187·74, df=13 (p<0·0001); I^2=93%								
Test for overall effect: Z=3·84 (p=0·0001)								
Website								
Kim et al (2016)[86]	1·20	1·50	92	0·60	0·80	90	4·0%	0·60 (0·25 to 0·95)
McLeod et al (2020)[88]	0·00	0·79	108	0·00	0·54	114	5·6%	0·00 (−0·18 to 0·18)
Ralston et al (2009)[90]	−0·90	1·10	39	0·20	1·10	35	2·8%	−1·10 (−1·60 to −0·60)
Ramadas et al (2018)[91]	−0·54	1·33	63	−0·57	1·33	55	3·0%	0·03 (−0·45 to 0·51)
Subtotal (95% CI)			**30**			**294**	**15·4%**	**−0·09 (−0·64 to 0·46)**
Heterogeneity: τ^2=0·28; χ^2=29·82, df=3 (p<0·0001); I^2=90%								
Test for overall effect: Z=0·33 (p=0·74)								
Total (95% CI)			**2290**			**2256**	**100·0%**	**−0·30 (−0·42 to −0·19)**
Heterogeneity· τ^2=0·05, χ^2=289·56, df=26 (p<0·0001); I^2=91%								
Test for overall effect: Z=5·34 (p<0·0001)								
Test for subqroup differences: χ^2=1·16, df=2 (p=0·56); I^2=0%								

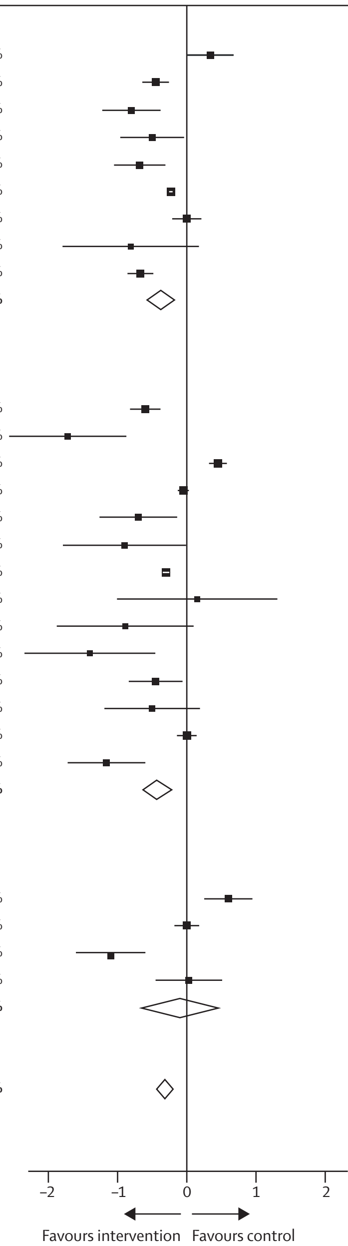

Figure 2: **HbA_{1c} meta-analysis**

Forest plot of mean difference in HbA_{1c} (expressed as percentage) between the digital health intervention and the usual care group, and subgroup analysis by mode of delivery of the intervention (ie, SMS, smartphone application, and website). The size of the squares indicates the weight of the evidence from each of the studies; studies with CI (horizontal line) crossing zero (vertical line) are inconclusive; powerful studies (those with more participants) have narrower CIs; the diamonds represent the summary effect sizes in each of the subgroups and in the overall sample, with the width of the diamond indicating the 95% CI. A statistically greater significant reduction in HbA_{1c} is seen in the digital health intervention group, compared with the control group in the overall sample and with the SMS and smartphone application modes of delivery but not when websites were used as the mode of delivery of the intervention. The data present substantial heterogeneity. HbA_{1c}=glycated haemoglobin A_{1c}.

	Mode of delivery	Percentage reach (randomly assigned proportion)	Uptake	Feasibility
Abaza and Marschollek (2017)[36]	SMS	12·7% (50·0%)	NR	Feasible based on high levels of satisfaction, acceptance, and improvement of clinical outcome (effectiveness)
Anzaldo-Campos et al (2016)[57]	Smartphone app	12·1% (66·8%)	75·0%	Feasible showing improvement of clinical outcomes (ie, declines in HbA_{1c} levels [effectiveness])
Argay et al (2015)[37]	SMS	NR (50·0%)	NR	NR
Arora et al (2014)[38]	SMS	15·4% (50·0%)	NR	NR; participant reported high satisfaction and would recommend TExT-MED to a family member or friend with diabetes; intervention was accessible, effective, and of low cost
Bender et al (2017)[58]	Smartphone app	11·8% (48·9%)	100·0%	Feasible based on achieving recruitment target (100%), high engagement (95·0% in intervention; 100·0% in control), retention threshold goals (100·0%), and adherence
Capozza et al (2015)[39]	SMS	NR (66·0%)	81·6%	Feasible based on high satisfaction among patients
Chao et al (2019)[59]	Smartphone app	3·8% (51·2%)	NR	NR
Dobson et al (2020)[40]	SMS	23·1% (50·0%)	NR	NR; reported on high acceptance and effectiveness
Dong et al (2018)[60]	Smartphone app	NR (50·0%)	NR	NR
Fang et al (2018)[41]	SMS	52·2% (51·9%)	NR	NR
Fortmann et al (2017)[42]	SMS	7·6% (50·0%)	NR	Feasible based on high acceptance, that participant would recommend Dulce Digital to a friend or family member with diabetes; intervention was clinically effective and cost-effective
Franc et al (2020)[61]	Smartphone app	NR (66·8%)	31·1%	NR
Frias et al (2017)[62]	Smartphone app	46·3% (69·5%)	86·0%	NR; reported only high satisfaction and adherence.
Gong et al (2020)[63]	Smartphone app	19·9% (49·7%)	98·9%	NR; reported that participants had good adoption of the programme and completed a substantial amount of chats with the intervention over 12 months
Goodarzi et al (2012)[43]	SMS	NR (50·0%)	NR	NR
Gunawardena et al (2019)[64]	Smartphone app	22·3% (52·2%)	>80·0%	Feasible based on usefulness and effectiveness
Hansel et al (2017)[83]	Website	43·8% (50%)	93·0%	Feasible based on high satisfaction (or appreciation) and ease of use among participants; 77% would recommend using the programme for patients like them
Heisler et al (2019)[84]	Website	18·3% (50·3%)	NR	NR
Hilmarsdóttir et al (2021)[65]	Smartphone app	39·1% (48·6%)	88·9%	NR; feasible as an add-on support for patients who are motivated to use technical solutions
Shariful Islam et al (2015)[48]	SMS	NR (50·0%)	NR	NR
Jaipakdee et al (2015)[85]	Website	78·3%	93·6%	NR; reported that 90·3% of the participants who had received the intervention were satisfied or very satisfied with it, and 59·0% intended to continue the programme, and 64·1% intended to recommend the programme to others; 80% of the primary health-care centres adopted the intervention
Kim et al (2016)[86]	Website	NR (50·0%)	NR	NR; reported only cost-effectiveness
Kim et al (2010)[44]	SMS	NR (50·0%)	NR	NR; reported high adherence or uptake, usability, and effectiveness
Kleinman et al (2016)[66] and Kleinman et al (2017)[67]	Smartphone app	41·5% (48·4%)	88·6%	NR; reported only satisfaction
Ku et al (2020)[68]	Smartphone app	43·5% (50·0%)	NR	NR; reported only the effectiveness
Kumar et al (2021)[69]	Smartphone app	25·9% (50·0%)	NR	NR
Lee et al (2020)[70]	Smartphone app	56·2% (56·9%)	54·0%	NR; reported only higher satisfaction
Leichter et al (2013)[87]	Website	NR (50·0%)	75·5%	Feasible based on practicality and acceptability (low dropout)
Li et al (2021)[71]	Smartphone app	46·2% (54·5%)	NR	Feasible based on adherence and effectiveness
Lim et al (2011)[45]	SMS	28·3% (33·1%)	NR	NR; reported patient satisfaction and other conveniences associated with the implementation
Lu et al (2021)[72]	Smartphone app	50·0%	NR	NR; reported only the effectiveness
McLeod et al (2020)[88]	Website	38·1% (50·1%)	91·6%	NR; reported only high cost associated with the programme and adherence

(Table 2 continues on next page)

	Mode of delivery	Percentage reach (randomly assigned proportion)	Uptake	Feasibility
(Continued from previous page)				
Omar et al (2020)[56]	Smartphone app	27·3% (50·0%)	NR	NR; reported high satisfaction with intervention; regarded as beneficial (80·0%) and convenient (67·0%), and agreed to continue to use it if it were to continue in the future (90%)
Or et al (2020)[73]	Smartphone app	33·3% (50·5%)	NR	NR
Pacaud et al (2012)[89]	Website	NR (69·1%)	NR	NR; reported only the satisfaction
Peimani et al (2016)[49]	SMS	25% (66·7%)	NR	NR
Quinn et al (2016)[74]	Smartphone app	NR (65·6%)	NR	NR; reported only satisfaction with the programme and engagement
Ralston et al (2009)[90]	Website	5·9% (50·6%)	76·0%	NR
Ramadas et al (2018)[91]	Website	34·6% (50·0%)	NR	NR
Ramallo–Fariña et al (2020)[46]	SMS	27·3% (74·9%)	NR	NR; reported on the necessity of patient empowerment and digital literacy to make the intervention successful
Sadanshiv et al (2020)[47]	SMS	37·4% (50·3%)	80·1%	Feasible based on high satisfaction, high percentage of users who received content (48·1%), received regularly (95·7%), read (93·2%), and acted (80·1%) on the SMS at 6 months
Shetty et al (2011)[50]	SMS	NR (51·2%)	NR	Feasible based on high acceptance, cost-effectiveness and practicability
Sun et al (2019)[75]	Smartphone app	NR	NR	NR; reported high overall satisfaction
Tamban et al (2014)[51]	SMS	41·6% (50·0%)	NR	NR
Tang et al (2013)[92]	Website	12·7% (48·7%)	88·0%	NR; reported low treatment distress, greater overall treatment satisfaction (27·7%) and willingness to recommend treatment to others
Vinitha et al (2019)[52]	SMS	48·3% (50·8%)	NR	NR; reported only acceptability
Waki K et al (2014)[76]	Smartphone app	40·9% (50·0%)	88·9%	NR; reported only effectiveness and convenience for patients
Wang et al (2019)[77]	Smartphone app	NR (50·0%)	NR (control: 100·0%)	NR; reported only effectiveness and reduction of hospitalisation cost
Wargny et al (2018)[53]	SMS	93·2% (both groups received intervention at different timepoints)	97·0%	NR; reported only convenience and suitability for a low-income setting
Whittemore et al (2020)[54]	SMS	21·1% (50·5%)	NR	Feasible based on high rates of recruitment, implementation fidelity, attendance, and attrition
Xu et al (2020)[55]	SMS	9·5% (50·8%)	63·6%	NR; reported on low cost, accessible, and facilitates high engagement for patients of different ages, health literacy, and socioeconomic levels
Yu et al (2019)[78]	Smartphone app	46·5% (50·3%)	NR	NR
Yun et al (2020)[79]	Smartphone app	42·1% (50·0%)	NR (control: 77·4%)	NR; reported only sustainability and cost-effectiveness
Zhang et al (2019)[80] and Zhang et al (2019)[81]	Smartphone app	56·5% (66·7%)	NR (frequencies of app usage in groups B and C were 10·7 [SD 9·5] times per week)	NR; reported only effectiveness
Zhou et al (2016)[82]	Smartphone app	NR (50·0%)	100·0%	Feasible based on effectiveness and high satisfaction rate
Zhou et al (2014)[93]	Website	NR (50·0%)	NR	NR

NR=not reported. app=application.

Table 2: **Reach, uptake, and feasibility of included interventions**

26 studies (4546 participants) were included in the meta-analysis on Hba_{1c}.[37,38,40,41,46–48,54–57,62,63,66–69,71,74–76,78,82,86,88,90,91] Data on secondary outcomes were not sufficient because they were not reported in enough of the primary research papers to warrant a meta-analysis. Of the included studies in the meta-analysis, five SMS interventions were assessed as high risk of bias,[38,40,47,48,55] and four as low.[37,41,46,54] The four website-based interventions were assessed as low risk of bias.[86,88,90,91] Regarding smartphone application interventions, six scored as low risk of bias,[56,67,68,76,78,82] five as high,[57,62,66,74,75] and two scored as having some concerns.[63,69] Overall, participants receiving a digital health intervention achieved a –0·30 (95% CI –0·42 to –0·19) percentage point greater reduction in HbA_{1c}, compared with those receiving usual care (figure 2). Smartphone application interventions produced the greatest HbA_{1c} reduction compared with usual care (–0·42% [95% CI –0·63 to –0·20]), followed by SMS (–0·37% [–0·57 to –0·17]).

Website-based interventions did not achieve a statistically significant HbA_{1c} reduction compared with usual care (–0·09% [–0·64 to 0·46]).

The heterogeneity between the studies was statistically significant (Q=289·56, p<0·0001) and considerable in magnitude (I^2=91%). The sensitivity analyses to assess the robustness of the effect estimate are described in the appendix (p 52). Publication bias was assessed via visual inspection of a funnel plot (appendix p 53). The data displayed a slightly skewed distribution. The asymmetry observed is due to an excess of smartphone application medium-sample-size interventions with positive effects on the outcome (HbA_{1c} reduction), but it does not indicate a serious publication bias.

Overall, the evidence was considered inconsistent due to the considerable heterogeneity of the study design (figure 2) and thus the level of evidence was downgraded (appendix p 9). Therefore, the overall score for the level of evidence was moderate.

43 studies reported an intervention reach based on the assessed population for inclusion into the studies (ie, the authors reported how many people in total they reached when recruiting for the intervention), with a median reach of 33·6% (range 3·8–93·2), whereas 15 studies reported only the randomly assigned populations, with a median of 50·6% (50·0–69·1) randomly assigned to the intervention groups (one study did not report reach). 21 studies reported intervention uptake, with a median uptake of 87·5% (31·1–100·0%). Smartphone application interventions reported higher reach compared with SMS and website-based interventions, but website-based interventions reported higher uptake compared with the other two intervention types (table 2).

The authors of 13 studies concluded that the interventions were feasible based on measures of meeting recruitment target, high response rate, retention, adherence, acceptance and compliance rates, efficacy, sustainability, fidelity, cost-effectiveness, usefulness, and high accessibility. Authors of 27 studies did not explicitly conclude that the interventions were feasible, but they did report high adherence, satisfaction, usability, convenience and engagement, high likelihood of recommending the intervention to others, high acceptance, and cost-effectiveness (table 2). We reported authors' interpretations of study feasibility as the components of feasibility measurement varied between studies.

Discussion

This systematic review synthesised the evidence of 56 studies on the effectiveness, reach, uptake, and feasibility of smartphone applications, SMS, and website-based interventions in 11 486 adults with type 2 diabetes. The meta-analysis of 26 studies (n=4546 participants) compared the three different modes of delivery and identified that smartphone application and SMS interventions were more effective in terms of glycaemic control than website interventions. Additionally, smartphone application interventions displayed the greatest reach, although website-based interventions had greater uptake.

Several reasons could explain the superior effectiveness that smartphone application and SMS interventions exhibited over interventions that were delivered via websites. First, due to technological advancements, modern smartphones include an array of capabilities, such as communication with wearable or ingestible sensors,[62,63] that permit continuous monitoring and can therefore improve results. Second, the synchronous communication abilities, such as video conferencing, allow health-care practitioners to intervene more rapidly than via asynchronous means.[12] Third, SMS and smartphone applications might be more user-friendly and easier to access due to the convenient and portable nature of mobile phones, as compared to websites that might require access to a laptop or desktop to engage with the services. In fact, studies have previously demonstrated that even between smartphones (eg, iPhones and Androids) usability factors determine the time required to complete health-related tasks.[95] However, other reports indicate that fixed devices are preferred over mobile ones, especially when the objective is to complete large tasks.[96]

Our meta-analysis found SMS and smartphone application interventions to be effective compared to usual care, in agreement with previous reports.[97–99] This finding means that either of these two modes of digital health intervention delivery can be used effectively and the decision regarding how to deliver the intervention should be based on the context of the intervention, the sociodemographic characteristics of the participants, and the behaviour that the intervention intends to target.

Participants' education level and higher baseline hyperglycaemia were both associated with larger reductions in glycaemia. This association is plausible, because of homoeostatic regulatory mechanisms, whereby the further a physiological value deviates from the typical range, the greater the homoeostatic pressure is to correct this deviation following intervention. This hypothesis also explains why in the study by Pacaud and colleagues,[89] a significant reduction in HbA_{1c} was only seen in male participants, because males included in this study had a higher baseline HbA_{1c} than the included females.[89] Future studies should incorporate effect modification analyses based on the baseline HbA_{1c} value. Regarding participants' education being a moderator of effectiveness, digital health tools were predominantly used for education, telemonitoring, and communication between participants and health-care professionals; therefore it makes sense that participants with a higher education status experienced the greatest benefit. However, it is known that the prevalence of type 2 diabetes is higher in populations of a lower socioeconomic and education status,[100] and future interventions should aim to optimise effectiveness in these populations. Several interventions translated their protocols to the mother tongue of participants to tailor the contents of SMS messages to the educational status and cultural background of their participants; however, this approach was not always successful, suggesting other reasons as being more important for the success of such interventions.[38–40]

Most study authors reported reach and adoption or uptake at the participant's level. Future studies should also report reach and adoption of the intervention at the implementer's level and at the broader community or cohort's level. We found comparing feasibility between the studies challenging, due to the inconsistency of implementation and evaluation metrics reporting. A comprehensive framework that combines several implementation guidelines and provides direction for how to operationalise evaluation and implementation framework components is needed. The absence of existing guidelines and frameworks' systematisation and agreement on construct naming and definitions did not permit a robust implementation evidence synthesis.

The included studies exhibited substantial heterogeneity. In addition to employing a different mode of digital health intervention delivery, studies used these tools in different ways. The simplest study designs included reminders to take medication. Education of participants was employed nearly universally. More complex study designs involved sophisticated real-time monitoring of biomarkers. Finally, some studies incorporated motivation and the delivery of comprehensive behavioural change interventions. Therefore, the superior effectiveness of smartphone applications could also be explained in terms of their capabilities to deliver all these approaches, compared with the other two tools that can only deliver some of them. Future programmes should leverage these increased capabilities to deliver holistic interventions.

Strengths of this review include the use of rigorous standard methodology as documented in the PRISMA and Cochrane guidelines for conducting systematic reviews and meta-analyses; a very large, demographically and culturally diverse population from 24 regions representing lower-middle-income, upper-middle-income, and high-income economy countries from six continents; the direct communication with study authors to derive accurate data for the analyses; the comprehensive series of sensitivity analyses performed to ensure the robustness of the calculated summary effect size; and the inclusion of implementation metrics.

This study also has limitations. First, searches were restricted to articles published in English. However, reports indicate that the difference is only one out of every 36 meta-analyses when the non-English publications are included.[101] Second, we searched five scientific databases for studies in adults. The adult filter is not consistent between these databases. In MEDLINE, the adult filter is 19 years of age or older, whereas for Embase and PsycInfo it is 18 years of age or older. This difference means that articles listed in MEDLINE with participants aged 18–19 years might have been missed, but the proportion of the population with type 2 diabetes at that age is small.[102] Third, most SMS interventions reported on frequency, but very few smartphone application interventions reported on the frequency of use of the application and time spent using it. Not having this data limits the analysis and conclusions on a dose-response relationship, because the frequency of application use appeared to moderate the effectiveness in one intervention,[61] in which only the participants that used the application more than once a week achieved a significant reduction in their HbA_{1c}. Future studies should examine this relationship further and ensure clear reporting of the frequency and time spent on engaging with the intervention. Fourth, some studies included more than one digital mode of delivery of the intervention. For example, Capozza and colleagues[39] reported conducting an SMS intervention but also employed a webportal where patients could view their data, and make associations between their behaviours and test results. This mode overlap poses a limitation when a comparison between modes is the objective. We respected the authors' report in terms of mode of delivery when deciding how to classify these studies, but we acknowledge the inherent limitation of this. Fifth, most studies reported on clinical parameters, such as HbA_{1c} and homoeostatic model assessment of insulin resistance, but very few studies reported on long-term clinical outcomes such as incidence of cardiovascular disease, amputations, and mortality. The duration of RCTs does not permit the examination of most of these outcomes, for which longitudinal studies are better suited. However, future studies should also explore how the different modes of digital health interventions compare in terms of the reduction of the risk of complications in people with diabetes. Sixth, studies in the mobile application group were on average more recent (2020) than those in the SMS (2017) and website (2016) groups, which might limit some of the conclusions—eg, regarding the uptake of the interventions. Seventh, there was great heterogeneity in terms of studies' objectives, ranging from simple participant education to tailored insulin dose titration, presenting another limitation for comparisons when the study design might have been optimised to the different objectives. Eighth, few studies assessed differences in outcomes between genders. Future studies should employ gender-based analysis to facilitate such understanding. Ninth, the evaluation of reach, adoption, and uptake is not able to be fully comprehensive in the context of the studies included in this review, as it is limited by the fact that these were not primary aims of the included studies. A future assessment in the context of a focused systematic review of these measures can help to evaluate the potential for translation to practice.

In summary, SMS and smartphone application interventions, but not website-based interventions, were associated with improved glycaemic control, compared with usual care, across diverse samples. At the same time, we recognise that there was considerable heterogeneity of studies. Considering that both smartphone application and SMS interventions are effective for diabetes management, clinicians should consider factors such as reach, uptake, patient preference, and context of the intervention when deciding on the mode of delivery of the intervention. Nine-in-ten people worldwide own a feature phone or a smartphone and can receive SMS, and six-in-seven people have access to a smartphone, with numerous smartphone applications being currently available for diabetes management. Clinicians should familiarise themselves with this modality of programme delivery and encourage people with type 2 diabetes to use evidence-based SMS and smartphone application interventions for improving their self-management of diabetes. Given the probable effectiveness of digital health interventions and their growing trend, clinicians can potentially leverage the high penetration rates and reach in diverse populations to deliver interventions.[103–108] This approach is of particular importance for rural and remote populations with limited health services and where diabetes prevalence is higher.[100,109] Future research needs to describe in detail the mediators and moderators of the effectiveness and implementation of these interventions, such as the optimal dose, frequency, timing, user interface, and communication mode to both further improve their effectiveness and to increase reach, uptake, and feasibility of treatments, as a number of included studies did not report on these. Finally, as our review included studies conducted in high-income, upper-middle-income, and lower-middle-income-economies, future studies should also examine the effectiveness of these interventions in low-income economies.

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Contributors

GM and YM conceptualised the study. GM and GS designed the methodology. GS, JJ, and EE did the data collection. GS and JJ did the data analysis. GS supervised the data collection and analyses. GS and GM did project administration. GM, RV, RW, LA, BO, and YM acquired funding. GS prepared the original draft of the manuscript. All authors edited and reviewed the final manuscript. All authors have read and agreed to the final version of the manuscript and to the decision to submit. All authors had access to all the data. GS and GM have verified the data.

Declaration of interests

LA received consulting fees from Mundipharma for advice on cost-effectiveness of SGLT2 inhibitors for the management of type 2 diabetes; honoraria from Boehringer Ingelheim and from Mundipharma for lectures on health economic aspects of diabetes; and is a member of the board of the AstraZeneca Foundation. All other authors declare no competing interests.

Data sharing

Template data collection forms, data extracted from included studies, and data used for analyses can all be made available upon request to George Siopis.

Acknowledgments

The DigiCare4You study has received funding from the EU's Horizon 2020 Research and Innovation Programme (grant agreement 945246). GS, GM, and DK received funding from the National Health and Medical Research Council (NHMRC) of Australia, as part of the NHMRC European Union Collaborative Research Grant Scheme, under the agreement with the NHMRC ID APP2007006. GS is a recipient of an Executive Dean Health Research Fellowship from Deakin University. RV declares receipt by New York University Grossman School of Medicine of a DigiCare4You funding subaward. The content of this Article reflects only the authors' views, and the EU is not liable for any use that may be made of the information contained therein. The authors of this Article wish to thank the authors of included original studies in this review and their statisticians who responded to communication and provided requested information or data. We also thank Meteda's representatives for participating in the initial meeting of the evidence synthesis committee (authors) for the planning of the systematic review. Meteda is a digital health company that develops medical and nutrition software for the management of diabetes. Privanova is a boutique privacy compliance and risk management consultancy. Meteda and Privanova are part of the DigiCare4You Consortium. Meteda and Privanova were not involved in the protocol development; searches; data collection, extraction, analysis, or interpretation; manuscript preparation; or decision to submit the manuscript for publication. None of the authors in this manuscript are associated with Meteda or Privanova. Finally, we thank the members of the DigiCare4You Consortium.

Editorial note: The Lancet Group takes a neutral position with respect to territorial claims in published text and tables.

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