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REVIEWS

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Mobile health applications for self-regulation of glucose levels in type 2 diabetes mellitus patients: a systematic review

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A – Study Design, **B** – Data Collection, **C** – Statistical Analysis, **D** – Data Interpretation, **E** – Manuscript Preparation, **F** – Literature Search, **G** – Funds Collection

Summary **Background.** As diabetes incidence continues to rise, active medical intervention and self-management have now become crucial. Evidence showed that diabetes patients are at high risk of developing complications. Self-care management is of utmost importance when it comes to diabetes care. Recent situations such as the COVID-19 pandemic, however, have restricted vital communications between diabetes patients and their caregivers. This factor significantly deteriorates the glycaemic control of diabetes patients. At this point, mobile health applications can tackle the mentioned problems.

Objectives. This article aims to investigate the recent developments in mobile applications for diabetes care. We also discuss the effectiveness of mobile health in controlling blood glucose levels through self-care for diabetes patients, especially during the pandemic.

Material and methods. We present a review derived from articles published in the last 8 years. We extensively searched major databases for articles related to mobile health applications for diabetes care.

Results. We found that mobile health applications are effective in diabetes self-management. Appropriate health applications enable communications between patients and caregivers/medical professionals at a distance, minimising the need for physical interactions during difficult circumstances. Via applications, patients can now maintain their healthy lifestyle through routine exercise reminders, food intake supervision and sleep quality monitoring. Certain health applications even allow users to interact with others having similar health situations so that they can be a motivation for each other.

Conclusions. Various studies showed that health applications help user to control blood sugar levels, which may come in handy to mitigate glycaemic self-control problems.

Key words: health, self-management, glucose, glycemic control, COVID-19 pandemic, diabetes mellitus.

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Background

Diabetes mellitus is a chronic degenerative disease that has become a severe problem in most countries, with the incidence continuing to grow from year to year [1]. Data from the International Diabetes Federation (IDF) shows that the prevalence of diabetes will increase by 84%, from 82 million in 2017 to 151 million in 2045 [2]. The IDF states that people with diabetes mellitus are at higher risk of experiencing many disabling and life-threatening health problems than people without diabetes mellitus. At a severe level, diabetes mellitus might completely stop the human body from producing insulin. Complications of diabetes mellitus may occur in all organs of the body. Diabetes mellitus causes mortalities through various complications, including coronary heart disease (50%) [3] and kidney failure (30%) [4]. As many as 30% of people with diabetes mellitus experience blindness due to retinopathy complications [5], and 10% of diabetes mellitus patients experience limb amputation [6].

To give an illustration of how serious the diabetes problem is, let us take a look at the diabetes case in Indonesia. Nowadays, Indonesia is ranked seventh worldwide in terms of diabetes occurrence, with diabetes patients reaching 10.7 million or 11.5% [7]. This figure is expected to rise to 13.7 million in 2030 and 16.6 million in 2045 [8]. Obviously, these numbers are significant. Diabetes is indeed reducing patients' quality of life. Moreover, not only has it caused discomfort and suffering for the patients and their families, diabetes has also caused notable financial burdens. This financial burden is more severe in a diabetes patient with foot ulcers (DFU) [9]. For example, at Cipto Mangunkusumo National General Hospital in Jakarta, Indonesia, in 2007, approximately 33% of diabetes patients were hospitalised due to DFU. These patients were linked to higher healthcare expenses and a longer average duration of stay [10]. Furthermore, according to a 2005 study, the average hospital stay for DFU patients in Indonesia was 45.3 days, with each patient having to spend more than 1.6 million IDR [11]. Ironically, the minimum provincial salary in Jakarta (where the hospital is located) in 2005 was 819,000 IDR, which is roughly half of the required cost for DFU patient care [12]. Normally, however, these amounts were (supposedly) enough to provide for the needs of two to four family members. The magnitude of the national financial burden caused by diabetes-related diseases can be seen from the number of insurance claims submitted to the national health insurance service (NHIS) of Indonesia. In 2015, the number of claims due to diabetes and its complications was one of the highest [13].

Self-care management is essential in diabetes control. Self-assessment is frequently viewed as unreliable despite being by far the most affordable and efficient method of self-care management. Patients with diabetes have demands that extend beyond just maintaining good glucose control and include pre-

venting complications, limiting their impairment and receiving rehabilitation. Healthy diet, exercise, blood sugar monitoring, adherence to medicine, strong problem-solving abilities, healthy coping mechanisms and risk-reduction behaviours are the seven fundamental self-care behaviours in people with diabetes that predict positive results [14]. All seven of these habits have been found to have a favourable relationship with stable blood sugar levels, fewer problems and an improvement in quality of life [15].

Among the abovementioned strategies, the four basic pillars of comprehensive diabetes treatment include nutritional consumption, pharmaceutical use, physical exercise and self-monitoring of blood glucose (SMBG) [16]. The ability to manage these four aspects in daily life to control and prevent diabetes complications is called diabetes self-management. Self-management is done to prevent complications that can be suffered by people with diabetes. Promotive and preventive measures through self-management, such as symptom management, disease prevention capability, wound care, physical exercises, socio-psychological and lifestyle changes and increased understanding of diabetes pathophysiology, are critical for the success of diabetes care. Appropriate diabetes self-management accelerates the healing rate and helps patients to prevent complications due to diabetes mellitus. Some challenges regarding self-care management of diabetes control have occurred. One of those main challenges is the awareness of the patients themselves. Without proper supervision from doctors, nurses or medical professionals, diabetes patients often neglect diet regulations and the required physical activities, leading to poor glycaemic levels. A study conducted in 2016 supported this statement by showing that type 2 diabetes mellitus patients often have low levels of self-care management [17]. Unfortunately, a low level of self-care management will increase the incidence of diabetes complications [17, 18]. The average patient compliance with long-term treatment of chronic diseases is only 50% in developed countries. This rate is even significantly lower in developing countries [19–21].

The COVID-19 pandemic has brought about unprecedented challenges to the healthcare system and has dramatically impacted the lives of people around the world [22]. Diabetes patients, in particular, have faced significant difficulties due to the lockdowns and isolation measures implemented to curb the spread of the virus [23]. These measures have limited their access to health care and reduced their ability to self-care and self-manage their condition.

One of the most significant impacts of the pandemic on diabetes patients is the disruption to their access to health care. With the lockdowns and travel restrictions, many diabetes patients have been unable to attend their regular check-ups and appointments with healthcare providers [24]. This has prevented them from receiving vital treatment and support, including medication refills, glucose monitoring and insulin injections. The lack of access to health care has also led to a delay in the detection and management of diabetes complications, putting patients at risk of further health problems.

Another major impact of the lockdowns and isolation measures on diabetes patients has been a reduction in their self-care and self-management efforts. Many diabetes patients rely on structured self-care routines, including regular physical activity, diet and glucose monitoring to manage their condition effectively. The lockdowns and isolation measures, however, have made it difficult for patients to maintain these routines, leading to a decline in their health and well-being [25]. For example, with the closure of gyms and parks, many diabetes patients have been unable to engage in regular physical activity, which is essential for maintaining glucose control. Similarly, with limited access to fresh and healthy food options, many patients have found it challenging to follow a healthy diet, which is crucial for managing their blood sugar levels. The lockdowns and isolation measures have also had a significant impact on the mental health [26] of diabetes patients. The stress and uncertainty caused by the pandemic have led to increased levels of anxiety and depression, which can negatively impact glucose control and overall health. Moreover, the isolation and lack of social support have made it difficult for diabetes patients to cope with their condition, leading to decreased motivation and self-care efforts.

During the pandemic, telemedicine has been the medical community's first response. Telemedicine enables medical professionals to provide assistance by phone or videoconferencing for mild-case patients in a safe environment and concentrate personal attention and limited resources on the most critical cases. By using the Internet and related supporting technologies, telemedicine links the accessibility, affordability and convenience of health-related information and communication [27]. During the COVID-19 pandemic, telemedicine has demonstrated its capability and effectiveness [28, 29]. The pandemic has given significant momentum to telemedicine development and adaptation. Before the pandemic, telemedicine was arguably underused, and their development rate is relatively stagnant. During the pandemic, however, stakeholders and companies are forced to quickly develop and provide support for adequate telemedicine applications. On the other hand, many medical professionals, as well as patients, were reluctant to use telemedicine prior to the COVID-19 pandemic. During the pandemic, they were forced to utilise telemedicine. As the pandemic situation has gradually been relieved, it is highly recommended that the telemedicine momentum should not be wasted and be continued, even after the pandemic has ended. Telemedicine utilisation can now be broadened to more diverse diseases. Diabetic conditions and other chronic conditions are all instances in which telemedicine can be applied in daily clinical practice [28, 29].

According to the study [30], there are now two prominent telemedicine strategies for diabetes care. First, it has been demonstrated that using mobile communication devices, such cell phones that are equipped with functions to carry out doctor's advice will improve patients' glycaemic control. With the help of these solutions, patients can receive instant medical professional support (e.g. such as mealtime optimisation and insulin dose calculation). Second, systems that combine an interactive Internet system with telecommunication capability between the healthcare professional and the patient through text messages or phone calls have also demonstrated some advantages for glycaemic management. The viability and effectiveness of telemedicine solutions for the care of diabetes patients have been the subject of various studies over the past ten years [31–34]. Nevertheless, comprehensive reviews of mobile health apps, particularly during the pandemic, are still lacking and thus need to be conducted.

Mobile health applications can be incredibly helpful for diabetes patients in self-management and self-care [35]. These apps provide real-time tracking of important health metrics, such as blood glucose levels, food intake, physical activity and medication schedules. Patients can also use these apps to monitor and track their glucose levels, food intake and physical activity, as well as set reminders for taking medication and receive feedback and personalised health recommendations. By having all of this information in one place, patients can have a more comprehensive view of their health, which can be incredibly valuable for managing their condition.

The COVID-19 pandemic has further highlighted the critical importance of mobile health applications for diabetes patients. With many in-person doctor appointments being cancelled or postponed, patients need to be more proactive in managing their health at home. Mobile health apps can provide the support that patients need to stay on track with their treatment plans, avoid potential health complications and manage their mental health. Additionally, many apps also have virtual counselling and support groups, which can be incredibly helpful for patients during this stressful time. Overall, mobile health applications are a crucial tool for diabetes patients to help them navigate the challenges of the COVID-19 pandemic and maintain their health and well-being.

In this article, we aim to systematically review the latest developments and the current evidence on the use of mobile health applications for self-regulation of glucose levels in type 2 diabetes mellitus patients. We also discuss its potential during the COVID-19 pandemic. We present a discussion on the advantages and limitations of these applications and how they can help diabetes patients manage their condition and maintain their health and well-being during this challenging time. The findings of this systematic review provide valuable insights into the potential of mobile health applications as a tool for diabetes self-management and self-care for diabetes patients, their families, caregivers, medical professionals, stakeholders and even mobile application developers.

Material and methods

This systematic review was carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol guidelines [36] to achieve the research objectives. We extensively searched 5 major databases (i.e. PubMed, Scopus, Science Direct, ProQuest and Clinical Key for Nursing) for articles related to mobile health applications for diabetes care. The search strings were 'Mobile Health', 'Application', 'Smartphone', 'Glycaemic Control', 'Self-management', and 'Type 2 Diabetes'. During the literature search stages, Boolean operators: "OR", "AND" and "NOT" were employed. Full-text studies published in English were eligible to be selected. Original papers, review papers, qualitative studies and case reports were eligible for inclusion. The publication range was limited to 2016–2023, meaning that only articles that were published in the last 8 years were considered. This article included only peer-reviewed publications with full-text papers available to the public. Note that patents, unpublished papers, commentary articles, editorial notes, raw data and preprints were excluded.

After the above searching strategy was implemented, the collected articles were then passed through inclusion-exclusion criteria to filter the selected articles. The included articles should focus on glycaemic control in adult patients. With the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) checklist [37], the components of the selected articles were assessed. The STROBE guide has 22 items broken down into 8 quality assessment criteria: sample size, sampling method, response rate, outcome measure, control analysis, study boundaries, ethical considerations and controls for confounding. Each study was given a score between 0 and 8 points, with 0 being the lowest possible score and 8 being the highest possible (0 points if no quality assessment criteria were met, and 8 points if all criteria were met).

Note that the STROBE checklist is not an instrument to measure the quality of the published article. Thus, STROBE checklist compliance does not necessarily reflect the article's quality and validity. However, the STROBE checklist enables us to assess the issues of the selected article [38] more thoroughly. In this article, we did not use STROBE assessment results as a base for the inclusion-exclusion criteria but rather as an aiding tool to investigate confounding, bias and generalisability of the selected article.

In this review article, the design of the selected studies varies from the qualitative study, review study, randomised control trial study, and case-control study. To appraise the quality of the selected studies, the Critical Appraisal Skills Programme (CASP) qualitative, review, randomised control trial and case-control study checklists were used depending on the study design of the article. CASP has been recommended by the Cochrane Qualitative and Implementation Methods Group tool and has become the most often used instrument for quality appraisal in health-related qualitative evidence syntheses [39]. CASP enables us to assess the strengths and limitations of the research methodology of the selected literature [40]. Further, CASP can be utilized to assess published papers' trustworthiness, relevance, and result [40]. Data from previously published literature was collected and analysed using the Population Intervention Comparison Outcome Study Design (PICOS) format.

Results

Database scanning turned up 242 possible relevant articles. A total of 197 articles met the requirements for analysis after 45 duplicates were removed. 68 publications were then accepted for full-text analysis, whereas 129 publications were rejected based on title screening (n = 27) and abstract quality assessment (n = 102). Finally, 13 papers were approved for evaluation after considering the eligibility criteria. Screening for the study is illustrated in Figure 1. Out of the 13 selected articles, 3 studies were conducted in Australia, 2 studies from South Korea, 1 study each from Qatar, India, Malaysia, Germany, Singapore, the USA, Japan and Thailand, and 1 study was conducted via a social media group with respondents from the US, the UK and Germany. Furthermore, 1 study was published in 2017, 1 in 2018, 4 in 2019, 2 in 2020, 3 in 2021, 1 in 2022, and 1 article was published in 2023, as stated in Table 1.

Table 1. Summary of selected studies

No.	Title	Author and year	Objective(s)	Method(s) (design, sample, variable, instrument, analysis)	Finding(s)
1.	Mobile Health Application-based Intervention for Improvement of Quality of Life Among Newly Diagnosed Type 2 Diabetes Patients	Patnaik et al., 2021 [41]	This study was conducted to obtain basic data related to the usefulness of the mobile health application and to observe whether diabetes self-management activities improved the quality of life of type 2 diabetes patients.	a. Design: Randomised control trial. b. Sample population: 66 patients diagnosed with type 2 diabetes (within 3 months of diagnosis). c. Variables: Self-management, *mHealth* app, diabetes mellitus. d. Instruments: Respondents were assigned to the intervention group and control group by block randomisation method. The intervention group was instructed to use the Android application, and the control group was instructed to use the website. e. Analysis: Data was imported and analysed with SPSS v20, and the Cochrane Q test was performed to analyse categorical data. The significance level was determined as ≤ 0.05.	This study suggested that a mobile-based application with a focus on diabetes self-management education could minimise diabetes complications and improve the quality of life of diabetic patients.

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No.	Title	Author and year	Objective(s)	Method(s) (design, sample, variable, instrument, analysis)	Finding(s)
2.	Nurse Coaching and Mobile Health Compared with Usual Care to Improve Diabetes Self-Efficacy for Persons with Type 2 Diabetes: Randomised Controlled Trial	Young et al., 2020 [42]	This study aimed to examine the impact of a novel intervention using motivational interviewing (MI) –based nurse health training combined with a wearable activity tracker that integrates patient-generated activity data into the patient's electronic health record (EHR) to improve health among adults with type 2 diabetes.	a. Design: Randomised control trial. b. Sample population: Participants from 2 suburbs and 1 urban primary care clinic within an academic health centre in Northern California living with type 2 diabetes. 155 patients were assigned to the control group, and 132 patients were assigned to the intervention group. c. Variables: *mHealth*, EHR, type 2 diabetes. d. Instrument: Diabetes self-efficacy (Diabetes Empowerment Scale (DES) – Short Form), an 8-item Likert scale survey instrument that measures diabetes-related psychosocial self-efficacy. e. Analysis: This study compared demographic and health-related characteristics between individuals in the intervention and usual care groups using the Student *t*-Test, Wilcoxon signed rank test, chi-square test and Fisher's exact test. The significance level was determined as ≤ 0.05.	This study demonstrated the short-term effectiveness of an innovative diabetes intervention using nurse health coaching and *mHealth* technology on diabetes self-efficacy and increased physical activity.
3.	Family Support-based Intervention Using a Mobile Application Provided by Pharmacists for Older Adults with Diabetes to Improve Glycaemic Control: A Randomised Controlled Trial	Poonprapai et al., 2022 [43]	This article aimed to evaluate the effectiveness of family support-based intervention via a mobile application by pharmacists on clinical outcomes, family behaviour, diabetes knowledge, self-management practices and medication adherence in older adults with type 2 diabetes.	a. Design: Randomised control trial b. Sample population: 157 participants, 78 of whom are assigned to the intervention group, and the other 79 are assigned to the intervention group. c. Variables: Diabetes, family support, mobile application, older adults. d. Instruments: HbA_{1c} measurement, blood pressure measurement, family behaviour: the revised version of Diabetes Family Behaviour Checklist, diabetes knowledge: General Knowledge of Patients with Diabetes, self-management practices: the modified version of the Summary of Diabetes Self-Care Activities Scale, medication adherence: pill count during the hospital visit. e. Analysis: Frequency with percentage (categorical data) and mean with standard deviation (continuous data) were used to present the subjects' characteristics. The chi-square test and *t*-Test were used to analyse the statistical difference between groups. Split-plot analysis of variance (ANOVA) was used to compare the results of both groups.	The study found significant improvements in the intervention group for glycosylated haemoglobin (HbA1c), blood pressure, family behaviour in diabetes care, diabetes knowledge, self-management practices and medication adherence. The study suggests that family support intervention via a mobile application by pharmacists is beneficial to diabetes care for older adults.
4.	Personalized Type 2 Diabetes Management Using a Mobile Application Integrated with Electronic Medical Records: An Ongoing Randomized Controlled Trial	Lee et al., 2021 [44]	This article aimed to compare the efficacy of a personalised lifestyle intervention based on a mobile phone application with regular care in participants with type 2 diabetes (T2DM).	a. Design: Randomised Control Trial. b. Sample population: 181 participants (of target accrual of 282 participants, ongoing). Participants were randomly assigned to one of three groups: (1) regular care; (2) mobile diabetes management; or (3) mobile diabetes management with a healthcare professional's feedback. c. Variables: Type 2 diabetes mellitus, digital health, *mHealth*, self-monitoring.	The findings suggest that mobile-based intervention and interactive communication between patients and healthcare providers might improve diabetes outcomes by complementing conventional management strategies.

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				d. Instruments: The intervention period was 26 weeks, followed by observation for 26 weeks. Participants were asked to fill in the information of age, sex, duration of T2DM, alcohol consumption, smoking history, dietary habits, physical activity, other comorbidities and medications, including anti-diabetes agents. Physical activities were assessed using the Korean version of the Global Physical Activity Questionnaire (K-GPAQ). e. Analysis: The obtained data was analysed using an analysis of covariance (ANCOVA), mixed-effect model repeated measures (MMRM) and a generalised linear mixed model (logistic GLMM).	
5.	The Role of Continuous Glucose Monitoring, Diabetes Smartphone Applications and Self-Care Behavior in Glycemic Control: Results of a Multi-national Online Survey	Kebede et al., 2019 [45]	This study aimed to investigate the determinants (with particular emphasis on continuous glucose monitoring device (CGM) use, diabetes app use and self-care behaviours) of glycaemic control among an online community of patients with type 1 and type 2 diabetes.	a. Design: Cross-sectional with a web-based survey. b. Sample population: People with diabetes using Facebook groups and diabetes-specific patient forums and through targeted Facebook Ads. c. Variables: Diabetes, CGM, self-care, glycaemic control, hyperglycaemia, hypoglycaemia. d. Instrument: Self-reported diabetes status, demographic characteristics, type of diabetes, medication use, self-care behaviours, self-reported blood glucose levels, use of CGM, self-reported confidence in diabetes self-management and perception of metabolic control were assessed in the survey. In addition, data on capillary blood glucose values and time of test (pre-prandial, post-prandial, etc.) was also obtained. Self-reported HbA_{1c} and capillary blood glucose data according to the time of measurement (pre-prandial, post-prandial) were assessed. e. Analysis: The self-reported glycaemic level data was then classified into three categories: hypoglycaemia, hyperglycaemia and good glycaemic control. Multinomial logistic regression stratified by diabetes type was performed.	The use of diabetes apps reduces the likelihood of experiencing hyperglycaemia in type 2 diabetes mellitus. Diabetes apps and CGM use can facilitate personalised medicine to help patients achieve individualised glycaemic goals.
6.	Usage Patterns of *GlucoNote*, a Self-management Smartphone App, Based on ResearchKit for Patients with Type 2 Diabetes and Pre-diabetes	Yamaguchi et al., 2019 [46]	This study aimed to develop *GlucoNote*, an app that uses Apple's ResearchKit to support self-management for patients with type 2 diabetes and pre-diabetes. The app does not require a prescription or intervention by medical professionals. The authors evaluated its usage patterns through a remotely conducted study.	a. Design: Experimental, before and after a comparative study. b. Sample population: 357 participants with inclusion criteria of all iPhone users aged ≥20 years in Japan with type 2 diabetes or pre-diabetes. c. Variables: Telemedicine, *GlucoNote*, self-management, diabetes mellitus. d. Instruments: Participants were asked to fill in the following profile information: gender, height, weight, wake-up time, sleep time, smoking habit, age at diagnosis, presence of retinopathy, presence of neuropathy and regular dental visits.	The authors developed and released *GlucoNote*, a new app that uses ResearchKit to support self-management in patients with type 2 diabetes and pre-diabetes. The study hinted at the promising potential of the *GlucoNote* for self-management for diabetes patients. Future work includes improving retention rates and evaluating its effects.

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				e. Analysis: To compare characteristics between power users and non-strength users. Fisher's exact test was used for categorical variables, and the Mann-Whitney U test was performed for continuous variables. Paired *t*-Test compared data between week 0 and week 4 for parameters with normal distribution, and Wilcoxon signed-rank test was used for parameters with non-normal distribution.	
7.	*M-Healthcare Model*: An Architecture for a Type 2 Diabetes Mellitus Mobile Application	Joshua et al., 2023 [47]	This research aimed to develop an architecture for mobile diabetes applications, a hardware block diagram design and an architecture of sensors for a type 2 diabetes mellitus mobile application.	a. Design: Experimental study. b. Sample population: 40 diabetes patients who were users of mobile-based diabetes applications. c. Variables: Android mobile applications, supporting hardware(s) and data monitoring. d. Instruments: Participants were asked to fill in the following factors of assessment evaluation: functionality, ease of use, usefulness, security and privacy and cost factors. e. Analysis: The results of the evaluation were then assessed using a Likert scale (strongly agree, agree, neutral, disagree, strongly disagree) with an assessment weight of 5, 4, 3, 2, 1.	The average value of factor functionality obtained from the participants' evaluation through the Likert scale was functionality = 4.57, ease of use = 4.67, usefulness = 4.75, security and privacy = 5.0, and cost = 4.70.
8.	Patients and Healthcare Workers Experience with a Mobile Application for Self-management of Diabetes in Qatar: A Qualitative Study	Abd-alrazaq et al., 2021 [48]	This study explored the experiences of patients and educators regarding their communication before and after the implementation of *Droobi*, a diabetes management app.	a. Design: Qualitative study to capture participants' experiences. b. Sample population: 9 patients and 5 nurse educators from the endocrine clinics at Hamad General Hospital and Women's Health and Research Centre. Patients were eligible for the study if they were 18 years of age or older, had any type of diabetes, were on insulin therapy, owned a smartphone, had Internet access, had no visual impairment and had adequate literacy levels and skills for use. c. Variables: Mobile application, self-management, diabetes mellitus. d. Instrument: In this study, the authors interviewed a convenience sample of 9 patients and 5 nurse educators. Before the interview, *Droobi* was downloaded to the participants' phones, and their profiles on the app were created. To ensure an optimal user experience, all participants received education on how to use *Droobi*. e. Analysis: The transcribed interview data was analysed using thematic analysis, which was conducted according to Braun and Clarke's guideline.	In this study, the authors stated that *Droobi* had the potential to improve communication between diabetes mellitus patients and the medical team, given its advantages over previous communication methods, thus improving self-management in diabetes patients.

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9.	Appropriation of Mobile Health for Diabetes Self-management: Lessons From Two Qualitative Studies	Rossmann et al., 2019 [49]	This study utilised a mobile phone appropriation model to examine how individuals with type 1 or type 2 diabetes integrate mobile technology into their daily self-management. This study advanced the field beyond mere usage metrics and a simple dichotomy of adoption versus rejection.	a. Design: Qualitative study with semi-structured interviews. b. Sample population: Study 1 was held in Singapore with 21 Singaporean diabetes patients (and pre-diabetes). Study 2 was held in Germany with 16 Deutsche patients with diabetes. c. Variables: *mHealth*, mobile phone, self-management. d. Instruments: Study 1 was conducted through 21 semi-structured face-to-face interviews (about 1 hour each, in English) with Singaporean type 1 and type 2 diabetes (and pre-diabetes) patients between December 2015 and September 2016. The interview guide was based on the MPA model and assessed the context of diabetes, general daily diabetes self-management and the use of web-based (mobile) devices as part of diabetes self-care. Study 2 was conducted through 16 semi-structured interviews with German individuals with diabetes. e. Analysis: The usability testing of *My Care Hub* was conducted. Using a convenient and thrilling sampling method, 12 participants (app testers) were contacted individually and provided with information about *My Care Hub* and the goal of its development. Testers were asked to rate the functionality of the app (performance of the analytics view). Participants were asked to use *My Care Hub* and provide feedback.	In this project, studies 1 and 2 revealed that the use of *mHealth* for diabetes self-management was not limited to the use of specific diabetes apps but rather encompassed the patient's entire mobile media ecosystem. Although diabetes apps play a notable role, especially for self-care and self-testing, diabetes patients use many more digital resources when managing their condition, such as lifestyle apps, messenger apps, traditional health information websites or forums accessed from a computer or mobile device. However, doctor-patient communication played only a minor role in this context and can even be a barrier to *mHealth* use, as doctors are reluctant to recommend the use of mobile apps. Among the reasons for diabetes patients to be reluctant to use *mHealth* for diabetes (continuously), financial, technical, cognitive and temporal issues were included.
10.	Mobile Phone Applications and Their Use in The Self-Management of Type 2 Diabetes Mellitus: A Qualitative Study Among App Users and Non-App Users	Jeffrey et al., 2019 [50]	This study aimed to evaluate the experiences and barriers of app use among people with type 2 diabetes mellitus (T2DM) and determine recommendations for improving diabetes app use.	a. Design: Semi-structured telephone interview. b. Sample population: Participants aged over 18 years from rural locations in Australia (RA2 or higher), with a self-reported diagnosis of T2DM for more than 6 months and smartphone ownership. c. Variables: Type 2 diabetes mellitus, mobile apps, self-management, smartphones, *mHealth, eHealth*, digital technology, user experience. d. Instrument: The interview was based on the Technology Acceptance Model, Health Information Technology Acceptance Model (HITAM) and Mobile Application Rating Scale. Participant demographics, including age, gender, education level, occupation, location, distance from a general practitioner (GP) and endocrinologist and diabetes management, were collected. Information on features contained in the apps used by participants was also recorded, including exercise tracking, timely medication administration, blood glucose level, diet monitoring and	The study revealed that features that were perceived as useful or facilitated use included a visual representation of trends, self-motivational encouragement, convenience and user-friendly design. A crucial conclusion was that it is important for healthcare professionals to be aware of apps as a self-management option and engage in their use to facilitate improved patient outcomes and education.

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				advice, self-management education, weight management, blood pressure monitoring and GP patient monitoring. e. Analysis: Interviews were transcribed verbatim by the person who conducted the interview. Data categorised within constructs was scrutinised to identify commonalities and differences in views and experiences across the range of participants. Data was analysed using deductive content analysis following the method by Elo and Kyngas.	
11.	User Retention and Engagement with a Mobile App Intervention to Support Self-management in Australians with Type 1 or Type 2 Diabetes (*My Care Hub*): Mixed Methods Study	Adu et al., 2020 [51]	This study aimed to evaluate participant retention and engagement with *My Care Hub*, a mobile app for diabetes self-management.	a. Design: Sequential explanatory mixed methods design with quantitative surveys and qualitative interviews. b. Sample population: Participants were people with type 1 or type 2 diabetes who used the health app intervention for 3 weeks. c. Variables: Mobile apps, engagement, retention, diabetes mellitus, self-management, behavioural intervention technology. d. Instrument: The study was conducted from August to October 2019, where each participant was given access to the app for 3 weeks. e. Analysis: A comparison of baseline characteristics between those who completed the study and those who did not complete the study was conducted using Pearson's chi-square test.	In this study, the interview results revealed the health application potential as a behaviour change intervention tool, especially as it facilitated participants' self-care efforts and increased their engagement with diabetes self-management activities such as blood glucose monitoring, physical exercise and healthy eating. Participants suggested additional functionalities such as extended access to historical analytics data, automatic data transmission from blood glucose meters and periodic updates of appropriate meals and nutrition to further enhance engagement with the app.
12.	The Development of *My Care Hub* Mobile-Phone App to Support Self-Management in Australians with Type 1 or Type 2 Diabetes	Adu et al., 2020 [52]	This study aimed to describe the development of *My Care Hub*, a mobile phone application (app) to support self-management in people with type 1 or type 2 diabetes.	a. Design: Descriptive report study. b. Sample population: Needs analysis study among multi-national audiences of type 1 or type 2 diabetics using a mixed methods study design. Through a convenient and thrilling sampling method, 12 participants (app testers) were contacted individually and provided with information about *My Care Hub* and the ultimate goal of its development. c. Variables: Mobile phone app, self-management, type 1 or 2 diabetes. d. Instruments: The usability testing of *My Care Hub* was conducted. Participants were asked to use *My Care Hub* and provide feedback. e. Analysis: Testers were asked to rate the functionality of the app (performance of the analytics view). The results from the first phase of usability testing were used for the refinement of the app prototype.	The development of *My Care Hub* involved a comprehensive process of healthy behaviour change identification, end-user needs, expert consensus, data security and privacy considerations. The app development process includes (1) selection of behaviour changes strategies; (2) user engagement; (3) expert advisor engagement; (4) data security and privacy considerations; (5) design creation and translation of outputs into a smartphone app; (6) two usability tests of a prototype version of the app.

Table 1. Summary of selected studies

No.	Title	Author and year	Objective(s)	Method(s) (design, sample, variable, instrument, analysis)	Finding(s)
13.	Content Analysis of Mobile Health Application on Diabetes Mellitus	Izahar et al., 2017 [53]	This study aimed to evaluate and compare the content and features of mobile medical apps for diabetes *self-management.*	a. Design: Literature review. b. Sample population: Out of 346 commercial apps, 16 (16%) and 19 (7.72%) diabetes apps were found in the Apple and Google Play stores, respectively. c. Variables: Diabetes, self-care, health informatics, mobile health, mobile application. d. Instrument: The inclusion criteria for the mobile apps were intended to be used for diabetes self-management, which allows users to record their blood glucose measurements using the app. Mobile apps that met all criteria were assessed for the availability of the features. e. Analysis: Mobile apps that met all criteria were assessed for the availability of certain features. One point was awarded for the availability of each feature, for a total score of 8.	This study showed that there are apps that track patients' medical records, especially blood glucose levels, and set reminders, which can improve diabetes control. Mobile apps have great potential in integrating patient self-care education and motivating patients to maintain healthy behaviours, thus helping them in managing their chronic diseases.

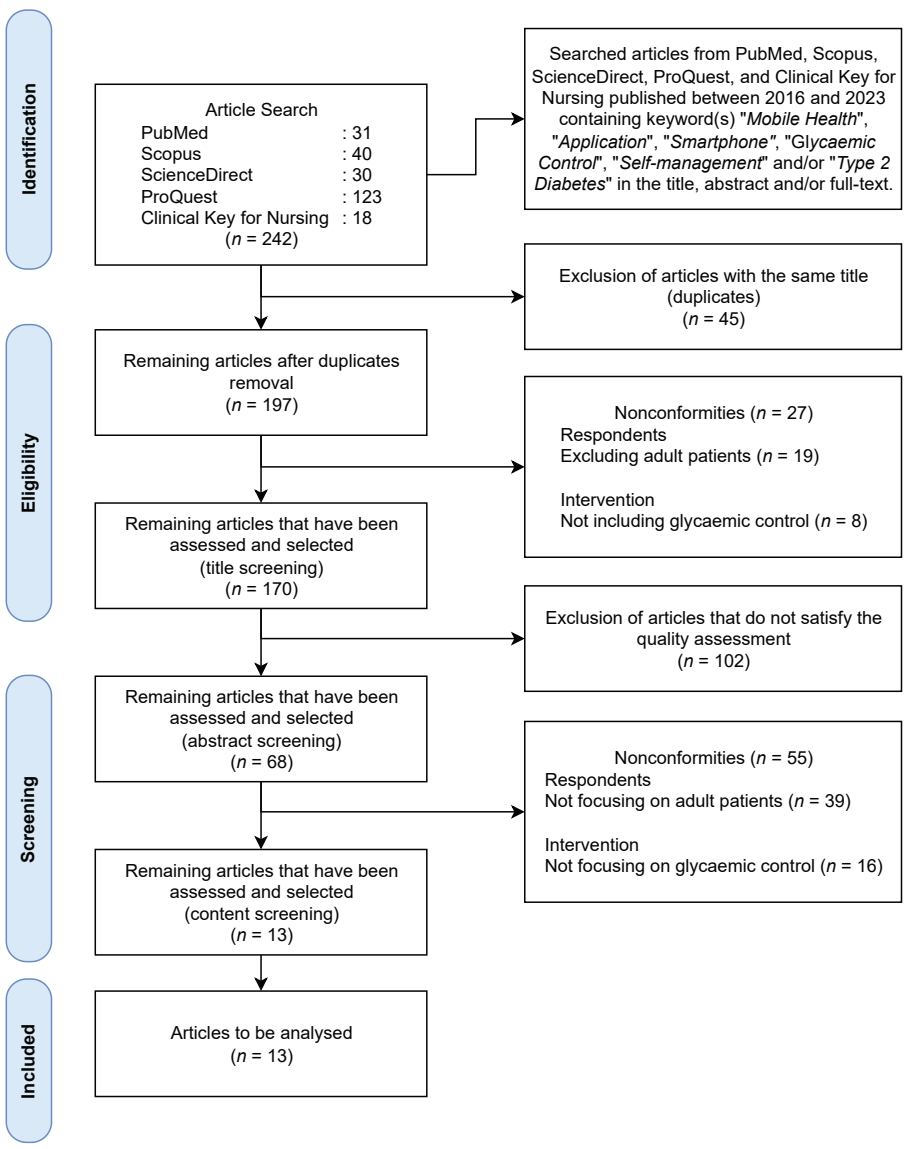

Figure 1. PRISMA flow diagram

Discussion

Developing and utilising mobile health applications to control glycaemic levels in patients with type 2 diabetes mellitus

Based on the reviewed articles, mobile health applications are mostly developed on the Android platform, while only some of them are developed on the iOS platform. By taking into account the number of Android users, which is larger than iOS users, this approach might be effective. By developing mobile applications on the Android platform, it is expected that the applications will reach a wider range of users than developing them on the iOS platform. Although it should be noted that cross-platform health applications (e.g. Android, iOS, web-based and even Windows and MacOS) are always preferred. Previous studies (Table 1) found that a good mobile health application should be easy to access, accurate, responsive, easy to use, have a decent interface and have social connections. Moreover, several users reported that they feel uneasy when using the mobile health application due to privacy and safety concerns. A mobile health application, particularly for diabetes care, should be able to ensure the privacy of the users and guarantee that the stored personal information and user health history are safe from cyber threats [52]. Thus, the users' confidence can be improved.

A widely adopted mobile health application might provide valuable input for stakeholders in formulating health policies related to non-communicable diseases (e.g. diabetes). Another goal that can be achieved through the implementation of mobile health is to close the health gap, which has so far been quite large. So far, diabetic patients who are in rural and remote areas have to spend quite a lot of effort just to visit health professionals and health facilities. Through digital technology, diabetes patients who are in rural and remote areas can get adjuvant health services (e.g. consultations, monitoring, etc.) without having to make a significant effort. In developing countries, many diabetes patients choose not to go to health facilities due to their financial shortage. By using mobile health applications, they can receive secondary health services without having to spend a large amount of money. This strategy is considered more effective and cost-effective than conducting extensive health checks [50]. There are many diabetes-related health applications that can be used for free and without requiring an active Internet connection. Many important features can be embedded in mobile health applications. Besides being able to detect diabetes mellitus as early as possible, the use of such health applications can also reduce the morbidity of diabetes mellitus [41]. Mobile diabetes monitoring (MDM) can provide more personal and flexible control facilities where doctors can immediately collect medical data and conduct continuous control of patient health, while patients can satisfy their desires to retrieve professional feedback and consultations [50]. However, it should be noted that health applications cannot replace the existence of doctors and health facilities, let alone routine check-ups, but can only be used as a medium to support diabetes self- care and self-management.

Types of mobile health applications to control glycaemic levels in type 2 diabetes mellitus patients

Diabetes self-control can be broken down into four aspects: education, physical exercise, diet therapy and medication. The ability to manage these four aspects in daily life to control and prevent diabetes complications is called diabetes self-management. Self-management is done to prevent complications that can be achieved by people with diabetes. Promotive and preventive measures through self-management, such as symptom management, disease capability, wound care, physical exercises, socio-psychological and lifestyle changes and increased understanding of diabetes pathophysiology, are critical for the success of diabetes care. Appropriate diabetes self-management accelerates the healing rate and helps patients to prevent complications due to diabetes mellitus.

Efforts to improve the adherence of type 2 diabetes mellitus patients with a diabetes care programme traditionally can be made through patient education, family (caregivers) supervision and interventions by health professionals. However, following the rapid development of information and communication technology, mobile health applications can now be employed to enhance patients' adherence. Mobile health applications enable technology-empowered medical self-care, health promotion and even telemedicine. As presented in Table 1, previous studies indicated that the use of mobile health could increase patients' awareness of self-care and allow them to actively contribute to treatment to optimise their health status, thereby minimising health complications. The most common embedded functions in diabetes care-related health applications are an insulin doses calculator and medication reminders, followed by glucose level monitors, telecommunication, food intake records and weight monitoring [53]. Self-management for patients with type 2 diabetes using mobile health applications has many benefits, including blood sugar level control and maintaining a healthy lifestyle (e.g. food intake, weight control, physical exercise, etc.).

Mobile health applications can also increase knowledge related to the prevention and self-care of type 2 diabetes patients. There are literally hundreds of diabetes-related mobile applications available. Among the applications that are commonly used to monitor glycaemic levels in diabetes mellitus patients are *GlucoNote, Droobi, My Care Hub, M-Healthcare Model* and many more. By using one of the mentioned applications, diabetes patients will be able to monitor, manage and control their diabetes. Several applications enable telecommunication between patients and healthcare providers while providing access to the latest diabetes education materials. Following the abovementioned applications, we picked five applications, each having their own unique features and advantages that we think are critical in diabetes-related health applications. These five applications will be discussed in the following paragraphs.

GlucoNote is an application that is developed based on Apple's ResearchKit to assist self-management for type 2 diabetes and pre-diabetes patients. *GlucoNote* does not require a drug prescription or healthcare professional intervention. *GlucoNote* allows the user to self-monitor their glycaemic data that they measure by themselves, the food intake information they manually enter and the step count recorded by the built-in pedometers on their iPhones, which are presented as graphs. Unfortunately, *GlucoNote* is only available for iPhone users, at least at the time this paper was written.

Droobi for Diabetes [48] is a multiplatform application developed to deliver digital care in the form of evidence-based digital care plans to support chronic disease self-management and empower patients and providers through various information technology solutions. When this paper was written, *Droobi* was available on website platforms, as well as iOS and Android platforms. The main features of the *Droobi* application are blood sugar check, nutrition tracker, movement (exercise) monitor and weight tracking. During sports activities, the user can press the "Get Moving" button, which will trigger *Droobi* to record and provide information on how much the user has exercised, how many calories were burned during exercise and what type of exercise (e.g. walking, running, cycling, etc.) was performed. However, we argue that the educational features of the *Droobi* applications are far from sufficient.

Among the diabetes-related applications that provide educational materials is *My Care Hub*. *My Care Hub* was invented as a platform to fulfil the needs of type 1 and type 2 diabetes patients by providing desired features and diabetes educational materials that could promote progressive knowledge and self-efficacy and encourage patients to fully participate in self-management activities. *My Care Hub*, according to the authors [51],

is arguably the first diabetes self-management platform aimed at the Australian population with type 1 or type 2 diabetes with a straightforward and comprehensive approach to its development based on theoretical and empirical principles of health behaviour transformation theories, user and medical expert involvement, privacy and data security considerations.

Lastly, we would like to highlight *M-Healthcare Model*, as this diabetes care mobile health application could interact not with only a glucometer and wearable band but also a treadmill and an exercise bike, two home physical exercise tools that are important and widely used for diabetes patients. This feature complements the generic features of diabetes-related mobile applications, such as the monitoring of medication, food intake, exercise and sleep.

The use of mobile health to control glycaemic levels in patients with type 2 diabetes mellitus during the COVID-19 pandemic

The COVID-19 pandemic has posed significant challenges to diabetes patients, making it difficult for them to access health care and self-manage their condition. Traditionally, diabetes patients themselves are already at high risk of infection and complications. Due to the emergence of the COVID-19 pandemic, diabetes patients are instructed to avoid direct contact with crowds and stay at home as much as they can to maintain their own health and safety. However, support for diabetic patients via cell phone or video is a major concern for the diabetes community [54], especially during the pandemic. In this context, mobile health applications have emerged as a critical tool for diabetes patients to self-manage their condition and maintain their health and well-being during the pandemic. Technology such as telemedicine and mobile applications has proven to be an effective tool in the COVID-19 pandemic [54]. Mobile health applications are proven to be effective in terms of time, effort and finance [55, 56].

Some of the literature (Table 1) discussing mobile health applications for diabetes mellitus are considered capable of helping with patient monitoring, although the results of the study are only short-term (temporary), and further research is needed to obtain more significant results. The integration of mobile health technology into existing information systems has the potential to further empower diabetes mellitus patients, improve the quality of community care services and increase efficiency in terms of time and cost [47, 48, 51].

One of the key ways in which mobile health applications can help diabetes patients is by providing real-time monitoring and support. These apps allow patients to track their glucose levels, food intake, physical activity and medication use, as well as receive feedback and guidance on how to manage their condition effectively. This information can be accessed and updated from the comfort and safety of patients' homes, reducing the need for in-person appointments and healthcare visits. Moreover, the apps can provide patients with personalised recommendations, alerts and reminders, making it easier for them to stay on track and self-manage their condition effectively.

Another advantage of mobile health applications is that they can facilitate communication and collaboration between patients and healthcare providers. With these apps, patients can send and receive messages, share glucose readings and other relevant data with their healthcare providers and receive feedback and guidance in real-time. This can greatly improve the quality and efficiency of diabetes care and reduce the need for in-person appointments. Additionally, mobile health applications can provide patients with access to educational resources, including information on diabetes management and self-care, which can help them better understand their condition and make informed decisions.

Mobile health applications can also help diabetes patients maintain their self-care and self-management efforts during the pandemic. With the lockdowns and isolation measures, many diabetes patients have found it difficult to maintain their usual routines, leading to a decline in their health and well-being. Mobile health applications, however, can provide patients with support and motivation to maintain their self-care efforts, even in the face of the pandemic. By tracking their progress, receiving feedback and guidance and connecting with others in similar situations, patients can feel more empowered and motivated to self-manage their condition effectively. Mobile health applications can also improve the mental health of diabetes patients during the pandemic. The stress and uncertainty caused by the pandemic can have a negative impact on glucose control and overall health. Mobile health applications, however, can provide patients with a sense of control and support, reducing stress and anxiety levels and improving their mental health and well-being.

The aforementioned advantages are expected to further improve patient self-management so that complications due to diabetes can be prevented and treatment costs can be reduced. Still, communication related to how to use and the features available in mobile health apps, especially in diabetes care, is a necessity so that users and health workers can use them easily and appropriately [13].

It should be noted that in addition to the mobile applications developers and stakeholders, the role of health workers is very important in promoting independent diabetes control innovations during the COVID-19 pandemic. Health workers should not be reluctant to use mobile health applications and instead should provide education and communication about such applications to diabetes patients. With mobile health applications, diabetes patients can still control diabetes without having to worry about safety when visiting health services during the COVID-19 pandemic. Mobile health applications can also reduce the hospital burden and workload, which have already been overwhelmed by COVID-19 patients. The utilisation of such applications can later organise the health information provided by patients, strengthen the relationship between the medical staff and the management of the centre serving diabetic patients and thus support the plans of the national health department. Since continuing to provide support for patient health in the future may be a challenging task, medical personnel are required to always be adaptive to the adoption of technology in the healthcare sectors [57].

Traditionally, healthcare professionals can provide adjuvant diabetes care in the form of preventive and rehabilitation measures. Professional support is a great motivation for diabetes patients to achieve promotion and prevention goals related to daily diet, physical activity control and blood sugar medication. In this context, nurses, for example, have the responsibility to help patients with type 2 diabetes through the transition to adapting to self-care programmes during the pandemic. Thanks to the availability of mobile health applications, nurses can independently plan interventions and deliver them to diabetes patients at home only through a mobile phone [46, 48–50].

Limitations of the study

The study limitations of our systematic review on the use of mobile health applications for self-regulation of glucose levels in type 2 diabetes mellitus patients during the COVID-19 pandemic include the following:

1. **Heterogeneity of the studies:** The studies included in the review varied in terms of their design, duration and target population, which can affect the comparability and generalisability of the findings.
2. **Limited number of high-quality studies:** The evidence base on the use of mobile health applications for diabetes self-management and self-care is still evolving, and the number of high-quality studies is limited.
3. **Short-term follow-up:** Many of the studies included in the review had a relatively short follow-up period, and further research is needed to assess the long-term impact of these applications on glucose control and health outcomes.

4. **Lack of generalisability:** Some of the studies included in the review were conducted in specific geographic locations or populations, and the results may not be generalisable to other settings or populations.
5. **Measurement bias:** The validity and reliability of the measures used to assess glucose control and other health outcomes can vary across studies and may impact the accuracy of the results.
6. **Non-randomised studies:** Most of the studies included in the review were observational in nature, and further research is needed to establish the causal relationship between mobile health applications and improved glucose control and health outcomes.

These limitations should be considered when interpreting the findings of this systematic review, and future research is needed to address these gaps in the evidence base.

Recommendations

Based on the findings of our systematic review, we recommend the following:

1. **For diabetes patients:** Patients with type 2 diabetes mellitus might consider using mobile health applications to help them self-manage their condition and regulate their glucose levels. However, they should also seek advice from their healthcare provider to ensure that the application is appropriate for their needs and that they are using it correctly.
2. **For medical professionals:** Healthcare providers should be aware of the potential benefits of mobile health applications for diabetes self-management and self-care and should educate their patients about the options available to them. They should also collaborate with mobile application developers to ensure that the applications meet their patients' needs and provide accurate and reliable information. They should also emphasise to the users that mobile health applications cannot replace physical examinations, the need for regular check-ups and medical intervention. Instead, they can only be used as a medium to assist patients in self-management and self-care.
3. **For mobile application developers:** Developers of mobile health applications for diabetes should focus on creating user-friendly, evidence-based applications that provide accurate and reliable information and support patients in self-managing their condition. They should also work with healthcare providers and patients to ensure that the applications meet the needs of their target population. In designing and developing mobile applications, they should always remember that patients' privacy and safety are their responsibility. They should ensure that the applications that they develop are safe, comply with ethical standards and are in accordance with the existing regulations.

Conclusions

Now that information and communication technology is advancing so quickly, mobile health applications can be more effectively used to improve patient adherence. Mobile health applications enable technology-empowered self-care medical treatment, health promotion and even telemedicine. Technology in diabetes treatment has the potential to support self-managed diabetes management programmes. Insulin dose calculators and medication reminders are the most often integrated capabilities in diabetes care-related health applications, followed by glucose level monitors, telecommunication, food intake records and weight monitoring.

The use of mobile health applications for self-regulation of glucose levels in type 2 diabetes mellitus patients during the COVID-19 pandemic has been shown to be a promising solution. Mobile health applications are needed as an innovation to manage diabetes care from home during the COVID-19 pandemic. The systematic review conducted highlights the potential benefits of such apps in providing patients with improved glucose control, increased access to health care and improved quality of life. The use of mobile health applications helps diabetes patients to manage their diabetes according to their condition and needs. Mobile health applications offer a range of interesting and innovative features that can be leveraged in the context of managing diabetes and reducing complications from worsening diabetes. Mobile health application developers play a key role in the success of diabetes management programmes. Several mobile health applications allow diabetics to communicate with each other, as well as with medical professionals and other diabetics, in forums when consulting and sharing experiences and stories. Contributions from healthcare professionals, as well as stakeholders, are also critical for the success of diabetes management programmes through mobile health applications. In addition, the role of health workers is crucial in promoting independent diabetes control innovations.

Previous studies found that a good mobile health application should be easy to access, accurate, responsive, easy to use, have a decent interface and have social connections. However, several users reported that they feel uneasy when using a mobile health application due to privacy and safety concerns. A mobile health application, particularly for diabetes care, should be able to ensure the privacy of the users and guarantee that the stored personal information and users' health history are safe from cyber threat. While mobile developers are responsible for these factors, stakeholder involvement is also needed to fully ensure the patients' privacy and safety. Strict guidelines and legal regulations should be formulated, followed by thorough monitoring of their implementation. Nevertheless, as the world continues to face the COVID-19 pandemic, the use of mobile health technology can play a crucial role in helping individuals manage their health, including those with type 2 diabetes mellitus.

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