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Review

Diabetes Mellitus—Digital Solutions to Improve Medication Adherence: Scoping Review

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Abstract: Medication adherence (MA) is a major problem. On average 50% of chronic disease management medications are not taken as prescribed While digital healthcare tools like mobile apps offer benefits such as informative messages and prescription management, they must be personalized and offer support across all medication phases to effectively address individual patient factors and optimize adherence, with room for further improvements. This scoping review examined the impact of digital health technologies on MA in adults with diabetes as well as their benefits and barriers. Using PubMed and Scopus databases, 11 out of 385 studies (2.86%) from January 2017 to August 2023 met the criteria for digital health interventions in diabetes MA, assessed through the Chronic Care Model. The Chronic Care Model (CCM) is a patient-centered, evidence-based framework designed to improve the care and outcomes for chronic illness patients, consisting of six core elements and enhanced by eHealth tools that facilitate self-management and support through digital innovations. The results demonstrate the effectiveness of digital health technology in improving medication adherence among adults with diabetes. Specific digital interventions, including mobile apps like Gather and Medisafe, SMS text messaging, telemonitoring, and tailored care management have demonstrated effectiveness in enhancing MA. These interventions have shown positive outcomes, including enhanced glycemic control and increased patient engagement. Some of the limitations, which these technologies face, are the poor usability, digital illiteracy among the patients, low rates of sustainability and low accessibility among the elderly population. Digital health technology shows promise in enhancing medication adherence among adults with diabetes, as revealed in this scoping review. However, ongoing research is necessary to fine-tune these interventions for improved outcomes and the overall well-being of individuals with diabetes. Additional improvement of the technologies and adaptation to the diverse population might be a good field for exploration.

Keywords: digital health; diabetes; medication adherence

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1. Introduction

Chronic diseases are the epidemic of twenty-first century. They are common, costly and some of them could be prevented. Primary care providers are looking for new and innovative approaches to prevent chronic diseases. The MedTech industry has been working intensively during the recent years to benefit healthcare with advanced technological solutions. Electronic solutions help patients and physicians in many areas, by controlling physiological indicators, monitoring patient status, improving dosage, enhancing adherence. Self-management, as an important part of chronic illness prevention and management has to include different techniques as this occurs outside the primary healthcare provider. Creating tools to help the individual develop life skills to support self-management will lead to improving the patient outcomes [1].

The Ascertaining Barriers to Compliance (ABC) taxonomy was developed with the aim of systematizing definitions and operationalizations of medication adherence [2].

Medication adherence is the procedure through which patients follow their prescribed medication regimens. It can be broken down into three measurable phases as follows: "Initiation", "Implementation", and "Discontinuation" [3]. Medication adherence refers to patients following the prescribed medication's timing, dosage, and frequency, which hinges on their understanding of their health condition and collaboration with healthcare providers [4]. The significance of adhering to medication has been acknowledged for a while, yet it was only about 50 years ago that it started receiving proper attention in clinical settings. Originally referred to as "compliance with therapeutic regimen," the concept evolved to "adherence to medication" to emphasize the patient's more active role [5]. Over time, it was realized that non-adherence stems from intentional and unintentional factors [6]. Implementing the medication adherence concept is delicate; identifying and addressing non-adherence is crucial for enhancing treatment. However, labeling patients as non-adherent doesn't effectively improve adherence rates [4].

Lack of medication adherence (MA) is a common problem, which endangers the effectiveness of healthcare systems. The collaboration of the patients in taking the prescribed medications is highly important for reaching the desired clinical outcomes. While most healthcare systems are able to provide accessible and efficacy medications, the non-compliance remains high [6].

In the International Diabetes Federation (IDF) diabetes Atlas states that 537 million adults (20–79 years) are living with diabetes (1 in 10 persons) and that it is expected to rise to 643 million by 2030 and 783 million by 2045. In Europe 61 million adults are living with diabetes (1 in 11 persons) with the expectation that this number will rise to 67 million by 2030 and 69 million by 2045 [7].

The percentage of diabetic patients who adhere accurately to prescribed oral hypoglycemic therapy varies significantly. Depending on factors like the studied population, treatment plan, and measurement method, the high adherence group can range from 38.5% to 93.1% of patients [8]. Several factors influence how well patients with T2DM stick to their medication regimen. The most consistent obstacles to treatment adherence for this condition involve the patient (such as depression and understanding of the disease and treatment), the treatment itself (including experiencing adverse reactions and the complexity of therapy), and the healthcare system (like difficulties in access and high medication costs) [9].

In cases of type 2 diabetes mellitus (T2DM), not taking medication regularly or following the correct schedule harms patients' health. It also raises healthcare costs due to poor control, more medical visits, higher expenses, and increased mortality. Ultimately, it leads to higher outpatient, ER, and hospitalization costs for T2D complications [10–13].

A systematic review conducted by Cheen and colleagues [14] showed a pooled primary medication non-adherence (PMN) rate of 10% for diabetes mellitus patients, and 12% and 14% for depression and asthma, respectively, which are the lowest compared to 25–43% for newly diagnosed patients with osteoporosis. The lower non-adherence of these patients is a result of the symptoms that are visible after non-compliance to the medication regimen [14]. In a study tracking over 11,000 veterans with T2D for at least 5 years, poor medication adherence (with medication possession ratio <80%) was significantly associated with inadequate glycemic control [15]. According to the National Health and Wellness Survey involving 1198 patients with T2D, each 1-point decrease in self-reported medication adherence (using the Morisky Medication Adherence Scale) correlated with a 0.21% increase in HbA1c, and increases of 4.6%, 20.4%, and 20.9% in physician visits, ER visits, and hospitalizations respectively [16].

Significantly, poor medication adherence in type 2 diabetes (T2D) has also been tied to higher mortality rates [13]. Similarly, Ho et al. found a significant connection between poor medication adherence in T2D and all-cause mortality over time [17].

Simple changes in the lifestyle of individuals could prevent type 2 diabetes. Early diagnosis and prevention could improve the results of the pre-diabetic population. Letting individuals have control over their health and support the self-management of the health with new technologies, would lead not only to the prevention of diabetes but also improve the quality of life [5].

The purpose of this narrative review is to search for evidence for the benefits of the digital health technologies used to improve medication adherence in adults with diabetes. The following questions were asked to guide the review:

1. Is there evidence that digital health technologies improve medication adherence in adults with diabetes?
2. What are the benefits and barriers of the digital health technology for medication adherence when used by adult patients with diabetes?

2. Materials and Methods

This scoping review follows five stages: (1) problem identification, (2) literature search, (3) data evaluation, (4) data analysis, and (5) presentation [18]. A literature search was conducted to find relevant studies published from January 2017 to August 2023.

One researcher conducted the search using: PubMed and Scopus. A combination of keywords was used, including "digital", "technology", "health", "diabetes", "medication", and "adherence".

For inclusion in this review, studies were required to explore a digital health technology intervention for medication adherence among patients with diabetes mellitus. The inclusion criteria encompassed the following: (1) randomized controlled trials (RCTs) that were peer-reviewed and conducted in English language, employing quasi-experimental, observational, or qualitative designs; (2) studies that involved digital health interventions aimed at enhancing adherence to prescribed medications among individuals aged 18 years or older; and (3) studies that specifically concentrated on diabetes type 1 and T2D.

On the other hand, studies were excluded if they met the following criteria: (1) lack of data regarding medication adherence; or (2) were classified as pilot studies. The process involved evaluating titles and abstracts to determine their relevance. Then, the selected studies were reviewed as full text publications.

In this scoping review, the Chronic Care Model (CCM) was employed to assess the utilization of digital health technology for enhancing medication adherence in diabetes. The MA interventions were categorized according to the CCM. We categorized the various MA interventions based on the components of the CCM. This aligned each intervention with the relevant CCM elements.

The Chronic Care Model (CCM) (Table 1) is a well-established framework focused on compassionate care for chronic illness patients. It emphasizes improving functionality and clinical outcomes. This patient-centered, evidence-based framework aims to reshape outpatient care and enhance healthcare results for those with chronic conditions [19–23].

Table 1. Chronic Care Model components and descriptions.

Chronic Care Model Components	Description
Self-management support	To empower patients to manage their health and cope with their condition.
Decision support	To promote clinical care that is consistent with scientific evidence and patient preferences.
Clinical information systems	To organize patient and population data to facilitate efficient and effective care.
Delivery system design	To ensure that care is coordinated, proactive, and patient-centered.
Community support	To mobilize community resources to meet the needs of patients.
Health systems	To create a culture and organization that promote high-quality care.

The Chronic Care Model consists of six core elements: health system or organization (HSHO), clinical information systems (CIS), decision support (DS), delivery system design (DSD), self-management support (SMS), and community resources for patients (CORP) [20,21,24].

The eHealth-enhanced CCM (eCCM) integrates digital health tools into chronic condition self-management. It assesses digital health innovations, extending beyond the traditional CCM by including eHealth tools and a broader definition of eCommunity, which covers various digital health support and education. The CCM and eCCM are interconnected, emphasizing the importance of eHealth [19].

Each digital technology for MA used in patients with diabetes was analyzed from the perspective of the CCM.

3. Results

3.1. Overview

Of the 385 abstracts, 11 articles (2.86%) that used a digital health intervention to promote medication adherence to prescribed medications for diabetes were selected in full text (Appendix A) and evaluated with the Chronic Care Model (see Table 2). Studies included eight RCTs, and three observational studies. Two studies were conducted in the USA, two in India, two in Spain, one in the United Kingdom, one in China, one in Singapore, one in Saudi Arabia, one in the United Arab Emirates. Medication adherence findings for the intervention and data extraction categories, including the study objective, design, sample, intervention length, and participant age, are included in Appendix A.

Strategies used to improve medication adherence included three primary approaches: SMS text messaging, telemonitoring and/or tailored care management, and web-based software. The subheadings in this section under "Utilization of the Chronic Care Model" consist of progressively interdependent components of the Chronic Care Model that influence patient-centered, evidence-based care and are designed to improve health outcomes by changing the routine delivery of care (ie, self-management support, decision support, clinical information systems, delivery system design, community support, and health systems) [25].

The examined research papers are shown in Appendix A, aiming to classify results according to components of the CCM, facilitating an evaluation of digital health interventions' impact on medication adherence. A summary of CCM elements used in each study is outlined in Table 2 [26–36].

Table 2. Chronic Care Model applied to studies.

Study Author, Year	Self-Management	Decision Support	Clinical Information Systems	Delivery System Design	Community Support
Kleinman, N.J. et al., 2017 [26]	X		X		
Huang, Z. et al., 2019 [27]	X				
Xu, R. et al., 2020 [28]				X	
Omar, M.A. et al., 2020 [29]					X
Almer, A. et al., 2020 [30]	X				
Shamanna, P. et al., 2020 [31]		X			
Katz, L.B. et al., 2022 [32]	X				
Lee, E.Y. et al., 2022 [33]	X				
Orozco-Beltrán, D., Morales, C. et al., 2022 [34]	X	X			
Al-Mutairi, A.M. et al., 2023 [35]			X		
Heald, A.H. et al., 2023 [36]	X				

3.2. Utilization of the Chronic Care Model

3.2.1. Self-Management

The objective of self-management support is to educate patients and families, providing training and health-related guidance to encourage self-care [25]. Additionally, the electronic Chronic Care Model (eCCM) introduces 24/7 accessibility, convenience, reminders, and notifications [19]. In a study conducted by Kleinman and colleagues [26], a m-Health app—Gather was found to improve medication adherence (39.0% vs. 12.8%;) and increase frequency of blood glucose (BG) self-testing (39.0% vs. 10.3%). The Gather m-Health platform offers a solution for individuals with diabetes, aiding in self-management and results in enhanced diabetes self-management [26]. In study by Huang and colleagues [27], the Medisafe app was evaluated and showed that the reduced obstacles to medication adherence in the intervention group. Although no improvement in HbA1c levels was observed, the app facilitated self-management and support in medication management, and it is likely to result in short-term enhancements in medication adherence [27]. In a study conducted by Alamer and colleagues [30], one-way automated SMS (OASMS) was assessed to study the effects of diabetes self-care messages delivered through non-tailored one-way automated SMS (OASMS) on managing blood sugar levels in type 2 diabetes). The study results revealed that the baseline HbA1c values were 10.2% in the intervention group vs. 9.9% in the control group. When adjusting for baseline HbA1c levels and age using an ANCOVA model, it was estimated that there was a reduction in HbA1c of −0.97% in favor of the intervention group. The study demonstrated the feasibility of using SMS for self-care messages in managing blood sugar levels, which again showed short-term improvement [29]. Similarly, RCT conducted by Katz and colleagues [32], aimed to showcase the effectiveness of the OneTouch (OT) Verio Flex glucose meter when used along with a Spanish-language version of the OT Reveal mobile app. The goal was to enhance diabetes care and enhance blood sugar control within an underserved Hispanic population dealing with type 2 diabetes. Over a period of 12 weeks, the individuals in the test group experienced a notable average decrease in A1C levels of 1.0%, which was considerably larger than the reduction seen in the control group). This improvement in A1C persisted during the following 12 weeks as well. Even those who switched to using the meter and mobile app showed significant enhancements in A1C. The intervention enhanced diabetes care, blood sugar control, and self-management within an underserved Hispanic population [32]. Another study conducted by Lee and colleagues [33] evaluated the impact of a mobile application that is integrated with an electronic medical record system, designed for personalized diabetes self-management. The focus of the assessment was on how this app affected glycemic control in individuals with type 2 diabetes mellitus, specifically in terms of self-monitoring of blood glucose levels and making lifestyle adjustments. The main measure of interest was the alteration in HbA1c levels after 26 weeks. Furthermore, the study also examined self-confidence in managing diabetes, engagement in self-care practices, and user satisfaction with the iCareD system after the intervention. The average reduction in HbA1c levels showed a significant decrease in HbA1c levels post-intervention. Furthermore, there was a substantial reduction in average blood glucose levels without an increase in hypoglycemic events The app supported self-monitoring of blood glucose levels and lifestyle adjustments, empowering individuals with type 2 diabetes [33]. Another study, an ambispective study (retrospective and prospective) was conducted by Orozco-Beltrán and colleagues [34] to examine how a home-based digital tool for patient empowerment and communication, known as the DeMpower App, impacts metabolic control of individuals with inadequately controlled type 2 diabetes mellitus (T2DM) over a 54-week period. The DeMpower app group showed a noticeable trend towards a higher proportion of patients reaching the study's glycemic target (46% vs. 18%). This trend became statistically significant when considering the target of HbA1c $\leq$ 7.5% (64% vs. 24%) or HbA1c $\leq$ 8% (85% vs. 53%). Additionally, improvements in other cardiovascular risk factors, medication adherence, and satisfaction were observed as well. The app empowered individuals with inadequately controlled type 2 diabetes for better self-management [34]. Finally, Heald and colleagues [36] conducted a RCT to assess how the Haelum app improved health outcomes and patient quality of life among patients with T2D over a 6-month period as well as if the app improved the patient's engagement levels [36]. Over 6 months, the treatment group's average HbA1c dropped by −7.4%, while the control group only saw a 1.8% decrease. Similarly, the treatment group's average BMI decreased by −0.7%, whereas the control group's average BMI reduction was −0.2%. A greater percentage of the active treatment group achieved reductions in both HbA1c and BMI compared to the control group. In terms of HbA1c, 72.4% of the active treatment group lowered their levels, while only 41.5% of the control group did Patients in the active treatment group also experienced an improvement in self-measured quality of life (QoL), as indicated by an average increase of 0.0464 in their EQ-5D-5L rating from pre-trial to post-trial. These results highlight that offering personalized care plans, along with support and education through a mobile app, can lead to reductions in HbA1c and BMI among individuals with T2D. The utilization of a patient management app, coupled with tailored care plans, also contributed to an enhancement in patient-reported quality of life (QoL) and engagement [36]. These studies emphasize the contribution of using digital technologies to medication adherence and self-management, key aspects of the Chronic Care Model in diabetes.

3.2.2. Decision Support

Decision support focuses on enhancing medical decision-making for healthcare providers and patients, with the aim of granting access to up-to-date care guidelines based on evidence [25]. Furthermore, eCCM covers topics like prompts and informational cues [19]. A study conducted by Shamanna and colleagues [31], examined the difference in hemoglobin A1c (HbA1c) in 64 patients with diabetes type 2 over a 3-month period using the Twin Precision Nutrition (TPN) program. The TPN machine learning algorithm utilized data from daily continuous glucose monitors (CGM) and food intake to offer personalized recommendations. These guidelines aimed to help patients steer clear of foods that led to spikes in blood glucose, suggesting alternatives that didn't cause spikes. In the 90-day follow-up, the program resulted in significant improvements in decision-making and glycemic control. HbA1c levels decreased from 8.8% to 6.9%, weight decreased, and fasting blood glucose levels improved. Physicians used the CGM data to make informed medication adjustments [31]. The ambispective study by Orozco-Beltrán and colleagues [34] for the DeMpower app implies that utilizing home digital tools for patient empowerment could have a meaningful impact on metabolic control. This app served as a home-based digital tool for patient empowerment, offering decision support for individuals with inadequately controlled type 2 diabetes. It helped patients make informed choices about their diabetes management. The study suggested that using home digital tools, like the DeMpower app, had a significant impact on metabolic control. This type of decision support is particularly valuable during situations like the COVID-19 pandemic and within the context of digital health advancements [34].

3.2.3. Clinical Information Systems

Clinical information systems serve the purpose of gathering, managing, and applying healthcare-related information, including patient registries and electronic medical records [18]. Furthermore, eCCM highlights the creation of patient portals, utilization of the Internet, mHealth, mobile phones, wearable devices, and patient health records [19]. Digital health technology enables potential integration of secure messaging, virtual appointments, remote monitoring with feedback, health risk assessment with feedback, prescription refills, personalized interventions, and connections to community initiatives [37]. The RCT conducted by Kleinman and colleagues [26], investigated the Gather app (m-Health diabetes platform) and the impact on the clinical outcomes, patient-reported outcomes, patient and provider satisfaction, and app usage. From the clinical information systems perspective of the Chronic Care Model, the Gather app serves as a tool that enhances information flow and communication between patients and providers. It offers the potential to improve access to high-quality care and empower patients to actively manage their condition. The study's positive outcomes suggest that such clinical information systems can contribute significantly to effective chronic disease management. [26]. A retrospective study in Saudi Arabia by Al-Mutari and colleagues [35] examined the impact of telemedicine on glycemic control (measured by HbA1c levels) in patients with type 2 diabetes during a specific period, particularly the COVID-19 lockdown. Telemedicine, as a component of clinical information systems, played a critical role in maintaining patient care during challenging times like the lockdown. It facilitated remote monitoring and communication between patients and healthcare providers, enabling the assessment of glycemic control. While the average HbA1c levels increased slightly, the study highlighted that a significant proportion of patients (63.1%) maintained or improved their glycemic control through telemedicine. The gender-based differences in outcomes also suggested that tailoring telemedicine interventions based on patient characteristics can be important. However, persistent elevated HbA1c levels in some patients may indicate the influence of other factors beyond telemedicine, such as lifestyle and comorbidities [35]. Both studies demonstrate the value of clinical information systems, including mobile apps and telemedicine, in supporting chronic care management. These systems enhance information exchange, patient-provider interactions, and monitoring, aligning with the Chronic Care Model's emphasis on proactive, well-informed, and collaborative care for chronic diseases like diabetes.

3.2.4. Delivery System Design

Delivery system design encompasses the significance of interdisciplinary clinical teams and the cooperation between patients and multiple healthcare providers [25]. Bluetooth-enabled devices and the utilization of chat, voice, and video communication enable the healthcare team to offer many aspects similar to a conventional in-person appointment. The incorporation of advanced technology offers an affordable and adaptable way to complement formal healthcare practices [37]. Ran and colleagues [28], conducted a study to evaluate the effectiveness of the EpxDiabetes automated phone calls or text messages as an intervention for patients with type 2 diabetes. The study assessed patient engagement and changes in HbA1c levels between the intervention group and the control group. The study demonstrated that the EpxDiabetes intervention led to increased patient engagement, with 58% of the intervention group actively responding to $\geq$25% of texts or calls over 4 weeks. This high level of engagement indicates that the delivery system design effectively reached and involved patients in their diabetes management. The intervention group showed an absolute reduction of 0.69% in HbA1c levels, particularly among patients with a baseline HbA1c level greater than 8%, where there was a significant decrease of 1.17%. In contrast, the control group had minimal HbA1c reductions. These findings highlight the effectiveness of the EpxDiabetes intervention in improving clinical outcomes, especially for patients with uncontrolled diabetes. The EpxDiabetes intervention's success in reducing HbA1c levels suggests that it promotes effective communication between patients and healthcare providers. This aligns with the delivery system design aspect of the Chronic Care Model, emphasizing the importance of well-organized, coordinated care delivery to achieve positive outcomes. Overall, Ran and colleagues' study showcases the value of a delivery system designed to facilitate automated communication with patients. It not only enhances patient engagement but also leads to significant improvements in clinical outcomes, particularly for those with uncontrolled diabetes. This approach aligns well with the Chronic Care Model's emphasis on organized, proactive care delivery to effectively manage chronic conditions [28].

3.2.5. Community Support

Community support connects patients to nearby resources and offers a chance for organizational leaders to forge new connections and broaden their reach. Within the eCCM framework, eHealth education is integrated as part of the eCommunity element, covering message training, health education, technology instruction, numeracy, literacy, usability, and security [19]. In the randomized two-arm parallel interventional study conducted by Omar and colleagues [29] over a 6-month period, a self-management education through social media network application (i.e., WhatsApp) was assessed. The study aimed to evaluate how a patient-centered diabetes education program, delivered via WhatsApp, influenced glycosylated hemoglobin (HbA1c) levels. Additionally, the research aimed to examine whether there was a correlation between health literacy, numeracy, and the outcomes of the intervention. This study aligns with the community support aspect of the Chronic Care Model by leveraging a social media network application (WhatsApp) to deliver diabetes self-management education. WhatsApp serves as a digital platform that can foster community-like interactions among participants. The use of WhatsApp for self-management education had a beneficial impact on glycemic control, as evidenced by a 0.7% reduction in HbA1c levels on average. This suggests that the intervention provided valuable support to individuals with diabetes in managing their condition. One noteworthy aspect is that the positive influence of social media on HbA1c levels remained consistent across patients with varying levels of health literacy and numeracy skills. This implies that the intervention was accessible and inclusive, addressing the needs of a diverse patient population. Overall, Omar et al.'s study demonstrates the potential of leveraging digital platforms like WhatsApp to provide community support for diabetes self-management. The positive impact on glycemic control, regardless of patients' literacy and numeracy skills, emphasizes the value of such interventions within the Chronic Care Model's community support framework [29].

3.2.6. Health Systems

The healthcare system establishes a context where organizational initiatives enhance patient care [25]. No studies were found that addressed the organization of healthcare and health systems.

3.3. Benefits and Barriers of Medication Adherence by Digital Health Technology 2

The second aim of this review was to determine the benefits and barriers of MA technology studied in adults with diabetes. Overall, the strongest benefit of digital health technologies to measure medication adherence involves patient engagement in diabetes and hypertension self-management through either one-way or two-way interactive reminders or educational information. Barriers to digital health technology for medication adherence in diabetes encompass limited smartphone access, staffing requirements, user engagement challenges, HbA1c level improvements, holiday season disruptions, digital literacy gaps, complex relationships between response rates and glucose levels, patient perceptions, message burden, scalability issues, time-limited interventions, age-related differences, one-way reminders, dietary maintenance difficulties, high costs, language and cultural barriers, legal concerns, patient experience, information access, low literacy (especially in the elderly), and training needs. The benefits and barriers are listed in Table 3.

Table 3. Benefits and barriers of digital health technology for medication adherence.

Study Author, Year	Digital Health Technology	Benefits	Barriers
Kleinman, N.J. et al., 2017 [26]	Gather app (m-Health diabetes platform)	• Improved medication adherence and blood glucose testing • Participants have high satisfaction for all aspects of the application	• The usage of smartphones is not among all the population • There should be an additional staff member, whose responsibilities will be to run the system in the hospitals • Users may become bored to using the application within the course of their treatment

Table 3. *Cont.*

Study Author, Year	Digital Health Technology	Benefits	Barriers
Huang, Z. et al., 2019 [27]	Medisafe app	• Improved medication adherence • Physician advocacy • Digital data collection	• No improvement in HbA1c levels • Holiday seasons impact • Digital literacy and usability
Xu, R. et al., 2020 [28]	EpxDiabetes	• Increased feeling of connection between patient-healthcare provider, which leads to better adherence to the therapy	• Complex relationship between response rate and fasting blood glucose • Patients' perception of benefit • Initial message burden before the adjustments • Scalability and physician feedback
Omar, M.A. et al., 2020 [29]	Self-management education through WhatsApp	• Improved glycemic control • Convenient access to Information • Effective communication • Inclusivity (regardless of literacy) • Higher engagement among younger • Cost-effective • Enhanced patient satisfaction	• Limited duration (6 months) • Age-related differences in response
Almer, A. et al., 2020 [30]	One-way automated short message service (OASMS)	• Reduction in HbA1c levels • Simplicity in messaging strategy • Potential impact on diabetes self-care • Enhanced patient satisfaction	• One-way reminders
Shamanna, P. et al., 2020 [31]	Digital Twin Technology-Enabled Precision Nutrition (TPN program)	• Personalized patient treatment • Precision nutrition guidance	• Patient experience difficulties in maintaining the low-calorie diet and the improvements cannot be maintained in the long-term
Katz, L.B. et al., 2022 [32]	OneTouch OT Verio Flex glucose meter	• The application is well tolerated within the underserved, low-numeracy, low-literacy population • Real time access of the patient data from the health care providers • The platform gives the opportunity of the health-care providers to make quick conclusions and decisions	• High expenses • Language and cultural barriers

Table 3. *Cont.*

Study Author, Year	Digital Health Technology	Benefits	Barriers
Lee, E.Y. et al., 2022 [33]	iCareD system	• High satisfaction of the participants from the iCareD program, which improves their self-care skills	• Age is a barrier to digital healthcare adoption
Orozco-Beltrán, D., Morales, C. et al., 2022 [34]	DeMpower app	• Improved metabolic control • Positive impact on HbA1c levels • Improved medication adherence	• Legal and logistical concerns • Patient experience and satisfaction • Information access
Al-Mutairi, A.M. et al., 2023 [35]	Telemedicine—virtual clinics	• Improvement in treatment satisfaction and glycemic control • Cost-effective solution	• Low literacy levels (elderly population)
Heald, A.H. et al., 2023 [36]	Healum Collaborative Care Planning Software and App	• Improved HbA1c levels • Improved patient self-reported QoL	• Digital literacy • Access to smartphones • Training and support needs

4. Discussion

4.1. Improvement of Medication Adherence Using Digital Health Technology

The results of this scoping review provide substantial evidence supporting the notion that digital health technology can significantly improve medication adherence among adults with diabetes. Several studies [26–28,30,32–36] demonstrated positive outcomes in terms of medication adherence through the use of various digital interventions. These interventions included mobile applications (e.g., Gather app, Medisafe app, iCareD system), SMS text messaging, telemonitoring, and tailored care management.

For instance, the Gather app [26] resulted in a substantial improvement in medication adherence, with a 39.0% adherence rate compared to 12.8% in the control group. Similarly, the EpxDiabetes intervention [28] led to increased patient engagement, with 58% of the intervention group actively responding to ≥25% of texts or calls over 4 weeks, and a significant reduction in HbA1c levels. The OneTouch OT Verio Flex glucose meter [32] demonstrated the effectiveness of the Spanish-language version of the OT Reveal mobile app in enhancing medication adherence and blood sugar control within an underserved Hispanic population.

The DeMpower app [34] showcased a noticeable trend toward improved metabolic control and medication adherence, with significant reductions in HbA1c levels. Furthermore, the Healdum Collaborative Care Planning Software and App [36] demonstrated improvements in HbA1c levels and patient-reported quality of life (QoL), highlighting the positive impact of digital interventions on medication adherence and overall well-being.

These findings collectively indicate that digital health technology can play a pivotal role in enhancing medication adherence among adults with diabetes, offering tailored solutions that range from reminders to self-monitoring tools, personalized care plans, and access to health information.

4.2. Other Similar Studies

In comparison to similar research studies, our scoping review contributes to the growing body of evidence supporting the use of digital health technology to improve medication adherence in diabetes patients. While previous reviews [38,39] have explored digital interventions' impact on medication adherence, our review utilizes the Chronic Care Model

(CCM) framework to categorize and assess these interventions comprehensively. CCM-based interventions, even without digital tools, effectively enhance clinical, behavioral, psychological, and diabetic knowledge outcomes, including medication adherence in diabetes patients [40]. Malaysia has successfully implemented the CCM, leading to improved patient outcomes and enhanced practice-centered care delivery [41].

As digital health advances, technology has integrated medication adherence strategies for chronic conditions like diabetes [40,42–44]. The CCM has been applied to various chronic conditions such as asthma, bipolar disorder, breast cancer, diabetes, hypertension, and obesity [19–25,40–45].

This is a continuation of the integrative review performed by Conway et al. [37] which covered studies published in the period between January 2006 and October 2016. This review examined various digital health technologies aimed at improving medication adherence in adults aged 18 and older with diabetes type 1 and type 2. These technologies included IVR, SMS text messaging, telehealth, and web-based software. In some cases, interventions involved one-way communication to the patient or two-way communication between patients and healthcare providers, often involving the timely reporting of monitored results like blood glucose and blood pressure. The study found that digital health technologies were diverse, and the populations studied varied in size, ethnicity, and age range. There is considerable potential for further improving patient-provider communication through emerging mobile and electronic media, particularly in populations accustomed to mobile phones, tablets, and similar devices.

Overall, our review corroborates and expands upon existing research by categorizing digital interventions within the CCM framework, offering a structured perspective on how these interventions align with established models of chronic care and improve medication adherence in diabetes patients.

4.3. Limitations and Strengths of This Research

This research paper has several limitations that warrant consideration. Firstly, the inclusion criteria limited studies to those published in English between January 2017 and August 2023 which is the period after the research conducted by Conway et al. [37] which covered studies published in the period between January 2006 and October 2016. Consequently, relevant studies in other languages or published before this timeframe may have been omitted, potentially introducing language and publication bias.

Additionally, while efforts were made to identify studies focused on diabetes, the exclusion of pilot studies and those lacking data on medication adherence rates could have excluded valuable insights. Furthermore, the heterogeneity of interventions and outcome measures across the selected studies may limit the ability to make direct comparisons between interventions.

On the positive side, this research paper adhered to a structured scoping review methodology based on the CCM framework, providing a comprehensive overview of digital interventions for medication adherence in diabetes. By categorizing interventions within the CCM, this research paper offers a novel perspective on how digital solutions align with established models of chronic care.

The selected studies collectively contribute to the evidence base supporting the efficacy of digital health technology in improving medication adherence among adults with diabetes. The positive outcomes reported in terms of medication adherence, glycemic control, and patient satisfaction highlight the strengths of these interventions in enhancing diabetes care.

4.4. Future Research Directions

Future research directions in the field of digital health interventions for medication adherence for patients with diabetes encompass several key areas to enhance their effectiveness and accessibility. Diverse populations: Future research should explore the impact of digital health interventions on medication adherence in diverse populations, including those with varying levels of health literacy, numeracy, and cultural backgrounds. This will help ensure that interventions are accessible and effective for all segments of the population.

Long-term effects: Investigating the long-term effects of digital interventions on medication adherence and clinical outcomes is essential. Studies with extended follow-up periods can provide insights into the sustainability of improvements and potential challenges over time.

Integration with healthcare system: Future research should explore strategies for the seamless integration of digital health interventions into existing healthcare systems. This includes addressing issues related to scalability, healthcare provider feedback, and the coordination of care.

Comparative studies: Comparative studies that directly compare different types of digital interventions (e.g., mobile apps, SMS, telemonitoring) can help identify which approaches are most effective for improving medication adherence in specific patient populations.

Cost-effectiveness: Evaluating the cost-effectiveness of digital interventions is crucial for healthcare decision-makers. Future research should include economic analyses to assess the value of these interventions in relation to their impact on medication adherence and health outcomes.

Patient-centered research: Engaging patients in the design and evaluation of digital interventions is essential. Future studies should prioritize patient-centered research approaches to ensure that interventions align with patient preferences and needs.

5. Conclusions

In conclusion, digital health technology holds great promise for improving medication adherence in adults with diabetes. While this scoping review provides valuable insights into the effectiveness of these interventions, continued research is needed to further refine and optimize digital solutions to enhance medication adherence and, ultimately, the overall health and well-being of individuals living with diabetes.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Diabetes Mellitus—Digital Solutions to Improve Medication Adherence: Integrative Review.

Autor, Year, (Country)	Sample, Intervention Length, Age and Study Purpose	Intervention	Medication Adherence Finding
Kleinman NJ et al., 2017 [26] (India) link	91 patients aged 18–65; 6 months. To assess the impact of an m-Health diabetes platform on clinical outcomes, patient-reported outcomes, patient and provider satisfaction, and app usage. RCT	Gather app (m-Health diabetes platform)	In the intervention group, more participants improved medication adherence (39.0% vs. 12.8%; p = 0.03) and increased blood glucose self-testing (39.0% vs. 10.3%) at 6 months. No other significant differences were observed.

Table A1. *Cont.*

Autor, Year, (Country)	Sample, Intervention Length, Age and Study Purpose	Intervention	Medication Adherence Finding
Huang Z et al., 2019 [27] (Singapore) Link	51 nonadherent and digitally literate patients with type 2 diabetes between the ages of 21 and 75 years, 12 weeks follow up. To determine the feasibility, acceptability, and clinical outcomes of using a smartphone app to improve medication adherence in a multiethnic Asian population with type 2 diabetes. RCT	Medisafe app	The intervention group had a lower post-study ASK-12 score. Medication adherence ranged from 38.3% to 100%, and most participants found the app easy to use.
Xu R et al., 2020 [28] (USA) link	65 patients, 6 months. To determine reduction of HbA1c and fasting blood glucose (FBG) among patients with type 2 diabetes mellitus (T2DM). RCT	EpxDiabetes	Intervention group saw a significant HbA1c reduction of 0.69%, especially for those with baseline HbA1c >8%. FBG decreased by 21.6 mg/dL in the intervention group. Engagement was 58% for the intervention and 48% for the control.
Alamer A et al., 2020 [30] (USA) Link	69 patients, ≥18 years; To evaluate the impact of diabetes self-care promoting messages via non-tailored one-way automated SMS (OASMS) on glycemic control in type 2 diabetes (T2DM). Observational	One-way automated short message service (OASMS)	ANCOVA model favored the intervention, showing an estimated HbA1c reduction difference of −0.97%. This suggests improved glycemic control in poorly controlled T2DM.
Shamanna P et al., 2020 [31] (India) link	64 patients, ≥18 years, 3 months follow up. To examine changes in hemoglobin A1c (HbA1c), anti-diabetic medication use, insulin resistance, and other ambulatory glucose profile metrics. Observational	Digital twin technology-enabled precision nutrition (TPN program)	Achieving a 1.9% HbA1c decrease, 6.1% weight loss, 56.9% reduction in HOMA-IR, reduced glucose time below range, and less diabetes medication use.
Omar MA et al., 2020 [29] (United Arab Emirates) link	218 patients (intervention and controlled group 109 each), aged ≥ 18, 6 months, To assess the effects on MA of self-management education through social media network application (i.e., WhatsApp). RCT	Self-management education through social media network application (i.e., WhatsApp)	After six months, HbA1c dropped significantly in the intervention group (7.7) compared to the control (8.4;). The intervention had a clinically significant reduction of 0.6%.
Laurence B Katz et al., 2022 [32] (Spain) link	81 subjects, aged ≥18, 6 months. To demonstrate the clinical value of OneTouch (OT) Verio Flex glucose meter used in combination with a Spanish-language version of the OT Reveal mobile application (app) to support diabetes care and improve glycemic control in an underserved Hispanic population with type 2 diabetes., RCT	OneTouch OT Verio Flex glucose meter	A significant 1.0% reduction in A1C was observed after 12 weeks, indicating improved glycemic control with the OT meter and app.

Table A1. *Cont.*

Autor, Year, (Country)	Sample, Intervention Length, Age and Study Purpose	Intervention	Medication Adherence Finding
Lee EY et al., 2022 [33] (China) Link	234 patients, ≥18 years, 6 months, to assess the effect of an electronic medical record-integrated mobile app for personalized diabetes self-care, focusing on the self-monitoring of blood glucose and lifestyle modifications, on glycemic control, RCT	iCareD system	At 12 weeks, HbA1c levels differed significantly among groups. HbA1c levels showed a statistically significant decrease after the intervention (UC vs. MC vs. MPC: −0.49% vs. −0.86% vs. −1.04%;).
Orozco-Beltrán D, Morales C et al., 2022 [34] (Spain) Link	50 patients, aged ≥ 18 and ≤80 years, observational: 52 weeks of follow-up and interventional: 52 weeks of follow-up, to analyze the effect of a home digital patient empowerment and communication tool (DeMpower App) on metabolic control in people with inadequately controlled T2DM, Observational	DeMpower app	The DeMpower app group showed a significant trend toward achieving glycemic targets, particularly HbA1c ≤ 7.5% and HbA1c ≤ 8%. Mean HbA1c was significantly reduced at week 24.
Al-Mutairi AM et al., 2023 [35] (Saudi Arabia) Link	4266 patients, aged ≥ 18, 3 months, to investigate the impact telemedicine had during this period on glycemic control (HbA1c) in patients with T2DM, RCT	Telemedicine—virtual clinics	In 24.9% of the patients HbA1c decreased by ≥0.5%, 36.9% of the patients whose HbA1c increased by ≥0.5% and 38.2% whose HbA1c changed by <0.5% in either direction. More males had significant improvements in glycemia compared to females (28.1% vs. 22.8%), as were individuals below the age of 60 years (28.1% vs. 22.5%). Hypertensive individuals were less likely than non-hypertensive to have glycemic improvement (23.7% vs. 27.9%). More patients on sulfonylureas had improvements in HbA1c (42.3% vs. 37.9%, whereas patients on insulin had higher HbA1c (62.7% vs. 56.2%). Patient groups exhibited varying changes in HbA1c, with notable gender and age differences. Hypertensive patients were less likely to have glycemic improvement, while medication types played a role.
Heald AH et al., 2023, [36] (UK) link	197 patients, aged ≥ 18, 6 months, to evaluate whether personalized care planning software and a patient-facing mobile app could improve health outcomes amongst patients with T2D through the delivery of personalized plans of care, support and education to allow patients to self-manage their diabetes more effectively, all accessible on a mobile device, RCT	Healum Collaborative Care Planning Software and App	The active treatment group had significant reductions in HbA1c (− 7.4%) and BMI (− 0.7%) compared to the control group (−0.2%). A higher percentage of the active treatment group improved their HbA1c and BMI, and quality of life also improved by an average of 0.0464.

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