International Journal of Innovative Medicine & Medicinal Plants Research
13(4):36-45, Oct,-Dec, 2025

 www.seahipublications.org ISSN: 2467-8538

doi:10.5281/zenodo.18076304

Efficiency of Digital Interventions in Diabetes Management: A Narrative Review

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ABSTRACT
Diabetes, a growing global health concern, necessitates long-term management strategies akin to those used for chronic conditions like hypertension. Despite established guidelines for glucose monitoring, lifestyle modifications, and medication adherence, compliance remains a challenge for many patients, leading to suboptimal outcomes. Digital health technologies, particularly the SmartCare mobile platform, present innovative solutions for improving adherence in diabetes management. This comprehensive review evaluates the role of digital health technologies in diabetes care, focusing on their functionality, benefits, limitations, and future directions. Literature sources were systematically classified and analyzed, comparing the impact of mobile health applications, telemedicine, continuous glucose monitors, and insulin pumps on glycemic control, patient engagement, and access to care. Digital interventions have shown notable success in enhancing glycemic control, often outperforming traditional primary care settings. Mobile applications, in particular, provide real-time tracking of health metrics, dietary feedback, and exercise guidance, significantly improving patient engagement and activity levels. Comparative studies highlight reduced HbA1c levels among users of these tools, affirming their efficacy in diabetes management. Discussion. The integration of digital tools within healthcare systems enhances accessibility, particularly for remote populations. However, challenges such as the digital divide and data privacy concerns persist. This review underscores the importance of personalized, adaptive strategies to optimize user engagement and effectiveness. Digital health technologies are transforming diabetes management by improving self-management and health outcomes. Future efforts should address barriers to access and incorporate AI-driven personalization for maximum impact, emphasizing a hybrid care model combining digital and traditional approaches.
Keywords: Digital health technologies; Diabetes management; Mobile health applications; Telemedicine; Self-management; Patient engagement.

INTRODUCTION

Diabetes is a chronic metabolic disorder marked by high blood glucose levels, which can cause severe damage to the heart, blood vessels, eyes, kidneys, and nerves over time. The most prevalent form is type 2 diabetes, primarily affecting adults, which arises when the body either becomes resistant to insulin or fails to produce enough of it. Over the last 30 years, the incidence of type 2 diabetes has surged dramatically

across countries of all income levels. Type 1 diabetes, previously referred to as juvenile or insulin-dependent diabetes, is a condition in which the pancreas produces little to no insulin. For individuals with diabetes, access to affordable treatments, including insulin, is essential for survival. There is a global commitment to stop the increase in diabetes and obesity by 2025[1].

Currently, approximately 422 million people worldwide have diabetes, with the majority residing in low- and middle-income countries. Each year, diabetes is directly responsible for about 1.5 million deaths. The number of cases and the overall prevalence of diabetes have been steadily rising over recent decades[1]. Diabetes mellitus is one of the most pressing public health challenges globally, affecting over 537 million adults and projected to rise to 783 million by 2045[2]. In Africa, approximately 1 in 22 adults (24 million) are living with diabetes, with the number predicted to increase by 129% to 55 million by 2045; over half (54%) of these individuals are undiagnosed, diabetes accounted for 416,000 deaths in 2021, and hyperglycemia affects 1 in 8 live births[2].

Effective management is crucial to prevent complications that can result in significant morbidity and mortality. Traditional diabetes management includes regular monitoring of blood glucose levels, adhering to medications, making dietary adjustments, and implementing lifestyle changes. However, many patients struggle to consistently apply these strategies, which can lead to poor glycemic control and a heightened risk of complications[3].

Digital health technology encompasses the use of digital and information technologies—including mobile devices, wearables, health information systems, software applications, and telehealth services—to enhance healthcare delivery and management. This broad range of tools is designed to improve the efficiency, accessibility, and quality of healthcare services while empowering individuals to take an active role in managing their health[4]. The roots of digital health technology date back to the integration of computers in healthcare during the mid-20th century, where they were initially employed for administrative tasks before expanding into clinical and patient care[5].

Digital health technologies have become valuable complements to traditional diabetes management, enhancing self-management, education, and patient engagement. These digital interventions offer real-time data tracking, tailored feedback, and improved communication with healthcare providers, all of which can lead to better patient outcomes. This review seeks to evaluate the effectiveness of these interventions by examining their advantages, supporting evidence, challenges, and potential future developments[6–8].

Types of Digital Intervention: Digital interventions for diabetes management can be classified into several main types, each providing distinct features and advantages.

***Mobile Health Application*.** Mobile health apps allow users to monitor multiple facets of their diabetes management, such as blood glucose levels, dietary intake, physical activity, and medication adherence. Well-known applications like MySugr, Glucose Buddy, and Diabetes offer features including carbohydrate counting, personalized coaching, and reminders for medication and blood sugar checks[9–11].

Research indicates that these apps enhance self-management by delivering immediate feedback on health behaviors. For instance, a study published in Diabetes Care found that individuals using a mobile health app experienced a more significant reduction in HbA1c levels compared to those receiving standard care[11–13].

Digital health solutions, especially mobile health applications (mHealth apps), are increasingly utilised to monitor patients remotely and provide healthcare services beyond traditional clinical environments[10]. Diabetes management has progressed significantly with the advent of smartphones, providing a wide array of applications, or “apps,” to support tech-savvy users. This fast-evolving landscape of mobile apps includes a diverse range of options, from beginner-friendly software to sophisticated programs intended for professional use. With the rise of smartphones, patients are increasingly leveraging mobile technology through automated text messages and a variety of applications, or “apps,” to monitor their health conditions. A multitude of mobile apps offering diverse features for diabetes management is now available, and the increasing number of tech-savvy patients has significantly boosted the adoption of these programs [14]. A recent study indicated that a smartphone glucose monitoring system holds considerable promise for enhancing glucose management among adolescents with type 1 diabetes[15].

Many diabetes management apps offer essential features, such as self-monitoring of blood glucose (SMBG), which allows users to log their glucose levels, alleviating the need to carry a physical record. Some apps enhance this capability with graphical displays of SMBG trends, aiding users in identifying and addressing hypoglycemic events related to medications, food, diet, and exercise[14,16]. Additionally, many applications include nutrition databases and carbohydrate tracking functions, enabling users to search for nutritional information by typing or scanning barcodes. For instance, apps like Diabetes Buddy, Diabetes Log, and Track3 provide extensive databases for quick access to carbohydrate content and calorie information.

The Calorie Counter by MyNetDiary further supports users by offering target planning and goal-setting features to help manage weight and caloric intake, with guidance from registered dietitians[17]. Research has shown that patients using smartphones to track their weight loss goals lost an average of 8.5 pounds more than those who did not use such technology over three-month intervals, highlighting the potential benefits for individuals motivated to manage their diabetes through lifestyle changes.

Moreover, data-sharing capabilities in apps like iBGStar Diabetes Manager and OnTrack enable users to email their data to healthcare providers and family members, fostering support and collaboration. Devices like iBGStar can also streamline the process by providing effective blood glucose measurement and logging through a single multi-use device, reducing the inconvenience of handling multiple tools[18].

Telemedicine. Telemedicine involves the electronic transfer of health information to enhance patient care and is divided into three main types. Synchronous telemedicine refers to real-time virtual consultations between patients and healthcare providers. Asynchronous telemedicine entails collecting medical data that is sent for evaluation at a later time. Remote monitoring involves the continuous collection of health data, such as from blood pressure monitors or continuous glucose monitors. The adoption of telemedicine surged during the COVID-19 pandemic[19]. Telemedicine enables virtual consultations between diabetes patients and healthcare providers, allowing patients to receive expert care without physically visiting a clinic. Through these virtual sessions, healthcare professionals can modify treatment plans, offer timely interventions, and track patient progress remotely. The advantages of telemedicine include greater accessibility for individuals in remote or underserved regions, minimized travel requirements, and improved convenience for managing chronic conditions such as diabetes over the long term[20–22].

Telemedicine plays a crucial role in diabetes care by ensuring regular follow-ups and continuous monitoring, which are vital for effective disease management. For example , current guidelines recommend consultations every three months to monitor HbA1c levels and adjust treatment[23], telemedicine offers a convenient and efficient way to meet these requirements without the need for frequent in-person visits. This is particularly important for patients with limited access to healthcare facilities or those living in remote areas. By facilitating timely adjustments to diabetes therapy and addressing cardiovascular risk factors, telemedicine helps ensure that patients receive the necessary care on a consistent basis, improving overall health outcomes. In relation to glycemic control, numerous studies have shown that telemedicine can enhance patient adherence to treatment plans and boost overall satisfaction. A systematic review revealed that telemedicine interventions contributed to a reduction in HbA1c levels by 0.3% to 0.5% among diabetes patients, demonstrating its effectiveness in managing the condition[24,25]. A meta-analysis of patients with type 2 diabetes found that remote monitoring led to a 0.6% reduction in A1C levels. The interventions employed in these studies varied, with some requiring regular communication between patients and healthcare staff. This frequent contact likely contributed to better adherence to treatment plans and more timely adjustments to therapy[26].

Wearable Devices. The global adoption of wearable and mobile technologies presents new opportunities for researchers to deliver healthcare and information in a portable and cost-effective manner. Among these technologies, smartphones are particularly noteworthy due to their advanced computational capabilities and widespread use. By 2019, an estimated 2.5 billion people owned smartphones, making them a powerful tool for extending medical care and health monitoring to a large portion of the population[27]. These devices enable the development of mobile health applications that can assist patients in managing chronic conditions like diabetes efficiently and affordably.

Regular smartphones are equipped with various sensors, including accelerometers (ACC), GPS, cameras, ambient light sensors, and microphones, which can gather data to assess user context. For instance, a smartphone's motion sensors, such as the accelerometer and gyroscope, can effectively measure physical activity levels and calories burned by the user. Wearable devices increasingly incorporate features that rival those of smartphones, with some models including built-in GPS, barometers, heart rate (HR) monitors, accelerometers, and gyroscopes. Moreover, wearables excel in detecting physiological indicators, such as heart rate, electrocardiograms (ECG), and skin temperature, making them particularly valuable for monitoring diabetes-related parameters[28]. This capability allows for more comprehensive tracking of health metrics, enhancing the management of diabetes and other chronic conditions.

Traditionally, individuals with diabetes have been required to monitor their blood glucose levels several times a day using a glucometer, or blood sugar meter. This process typically involves pricking the finger to obtain a small blood sample, which the glucometer then analyzes to determine glucose levels[29]. While this method can be effective for managing diabetes, not everyone is comfortable with the frequent finger pricks. Wearable technology for diabetes management provides a viable alternative. The two primary types of wearable technologies include continuous glucose monitoring (CGM) systems, which track glucose levels continuously throughout the day, and insulin pumps, which automatically administer insulin doses as needed, eliminating the necessity for self-injection. These innovations significantly enhance the convenience and comfort of diabetes management, making it easier for patients to maintain optimal glucose control[30,31].

In the healthcare field, "diabetes technology" refers to the devices and software that individuals with diabetes use to manage their condition. This technology is primarily categorized into two areas: insulin administration and blood glucose monitoring. Insulin pumps are the most widely used devices for administering insulin, while continuous glucose monitors (CGMs) are commonly used to track blood glucose levels. Recently, hybrid devices that combine both functions have been developed, offering a more integrated approach to diabetes management. When used correctly, these technologies can significantly enhance the quality of life for patients. However, the complexity of these devices and the rapid advancements in this field present challenges to their broader adoption by patients[32].

Continuous Glucose Monitors (CGMs). The CGM systems offer a more efficient way for people with diabetes to track their blood sugar levels compared to traditional glucometers, which require frequent finger pricks. CGMs use a sensor placed under the skin to continuously monitor glucose levels, eliminating the need for multiple daily tests. The device transmits data to a smartphone, providing real-time glucose readings and alerts for trends toward high or low blood sugar[31]. This continuous tracking helps individuals take timely action to prevent complications, improving overall diabetes management. Additionally, CGMs are convenient for daily use, even during activities like swimming or showering.

Insulin pumps. The insulin pumps offer a convenient alternative to multiple daily injections for people who need insulin to manage their diabetes. These small devices deliver insulin through a cannula placed under the skin, providing a continuous dose (basal insulin) and additional doses (bolus insulin) when needed. Pumps can integrate with smartphones for easy monitoring and, in some cases, with Continuous Glucose Monitoring (CGM) systems to automatically adjust insulin based on glucose levels[33–35]. This technology helps patients maintain better control of their blood sugar, while also providing valuable data for doctors to adjust treatment.

Benefits of Digital Interventions

Numerous studies have shown that digital interventions can greatly enhance glycemic control in individuals with diabetes. Tchero et al. found that telemedicine improved patient cooperation in treatment and aided in glycemic control. In their study, telemedicine interventions reduced HbA1c levels by approximately 0.48% in patients with type 2 diabetes, compared to those receiving standard care[36]. Several recent studies have examined the feasibility of using various E-health interventions, such as PC, SMS, or smartphone applications (SA), for managing type 2 diabetes. However, these studies have not thoroughly determined which specific form of E-health intervention is most effective in improving

glycemic control[37]. Interventions that provide continuous support and personalized educational content offer distinct advantages for self-management and blood sugar regulation[38].

Continuous Glucose Monitors (CGMs) have been shown to reduce HbA1c levels by providing real-time glucose readings, allowing for more timely insulin adjustments. One study demonstrated that the use of CGM devices led to significant improvements in glycemic control, with mean HbA1c levels dropping from 11.21% to 7.04% and average blood glucose levels decreasing from 286 mg/dl to 158 mg/dl. Additionally, the occurrence of hypoglycemic events was significantly reduced, with mild hypoglycemia decreasing from 4.75% to 0.78%, and severe hypoglycemia from 3.01% to 0.2%[39].

Enhanced Patient Engagement. Digital interventions promote active patient involvement in managing diabetes. Real-time feedback, data visualization, and personalized health insights encourage users to take ownership of their condition. By receiving immediate alerts and feedback, patients are more likely to adhere to their treatment plans and make informed decisions about their lifestyle and medication[40,41]. Unlike generic approaches, these digital solutions are tailored to meet individual needs, preferences, and health profiles. By leveraging patient data such as blood sugar levels, heart rate, blood pressure, weight, and behavioral information like exercise routines, dietary habits, and sleep patterns, these interventions can identify trends in blood sugar fluctuations and assess potential risks. As a result, they provide personalized educational content, dietary recommendations, medication reminders, and exercise plans, empowering patients to manage their diabetes in a way that fits their unique circumstances[42]. Digital health allows patients to access support and education from the comfort of their homes or wherever they are, providing a convenient and flexible option for diabetes management. This accessibility is especially valuable for those in rural or remote areas, where access to specialized diabetes care and resources may be limited[40].

***Accessibility*.** Digital tools are highly accessible and can extend diabetes care to remote or underserved populations. Telemedicine, for example, provides patients in rural areas with access to specialist care, which can be critical for managing complex conditions like diabetes. Moreover, mHealth apps and wearables are becoming increasingly affordable, making them more available to diverse populations[43,44].

While telehealth has the potential to improve health outcomes for individuals with diabetes, there are several limitations to consider. Those from lower socio-economic backgrounds, living in rural areas, or with limited English proficiency may face challenges in accessing or effectively communicating during telehealth visits. To better serve these underserved populations, additional support systems are necessary to ensure both patients and providers can use telehealth in a more effective and less burdensome manner[45].

Cost-Effectiveness. Digital interventions can significantly reduce healthcare costs by minimizing the frequency of hospital visits, lowering the risk of diabetes-related complications, and promoting better self-management. Continuous monitoring and virtual care options enable early detection of potential issues, reducing the need for in-person consultations and emergency care. This offers a more cost-effective approach for both patients and healthcare systems, streamlining care delivery while improving health outcomes[21,46,47]**.**

Challenges and Limitations

Digital Divide. Despite the potential of digital interventions, disparities in access to technology remain, especially among older adults, low-income individuals, and those in rural areas. This "digital divide" results in unequal access to these tools, potentially limiting their benefits for certain populations who may struggle to afford or effectively use digital health technologies.[48].

***User Engagement and Retention*.** Although digital interventions provide substantial advantages, sustaining user engagement over the long term can be difficult. Research indicates that after an initial surge of interest, usage often decreases. To enhance long-term engagement, incorporating strategies like gamification, tailored reminders, and social support features could be effective in addressing this challenge[49,50]**.**

Data Privacy and Security. The increasing reliance on digital tools in healthcare brings significant concerns regarding the privacy and security of personal health data. Safeguarding sensitive information,

such as glucose levels and treatment plans, is crucial for preserving patient trust and ensuring compliance with privacy regulations, such as the Health Insurance Portability and Accountability Act (HIPAA). Implementing robust security measures is essential to protect against unauthorized access and data breaches[51–53].

Future Directions.

Integration with Traditional Care. To fully leverage the advantages of digital interventions, it's essential to integrate them with conventional in-person care. Hybrid models that blend face-to-face consultations with virtual monitoring and feedback can provide optimal results by guaranteeing that patients receive continuous and personalized care[54,55]. This integration ensures a comprehensive approach to diabetes management, enhancing overall patient outcomes.

Personalization and Adaptation. Artificial intelligence (AI) and machine learning (ML) offer significant potential for customizing digital interventions to meet the individual needs of patients[56,57]. By analyzing extensive datasets, these technologies can forecast glucose fluctuations, suggest dietary modifications, and optimize medication regimens, thereby enabling a more tailored approach to diabetes management.

DISCUSSION

The integration of digital health technologies into diabetes management has significantly advanced the ability of patients to manage their conditions effectively. Traditional approaches to diabetes care often require constant self-monitoring, medication adherence, and significant lifestyle changes, which many patients find difficult to maintain over the long term. Digital interventions, including mobile health applications, telemedicine, and wearable devices, have emerged as vital tools to support patients in overcoming these challenges. One of the most widely used telemedicine tools in diabetes management is video consultations. Video consultations have been found effective and reliable means of communication for medical purposes. Such surveys show that patients advise such telemedicine as an alternative.

Telemedicine has been instrumental in increasing accessibility to diabetes care, particularly for individuals in remote or underserved regions. It offers patients the opportunity to consult with healthcare professionals without the need for frequent in-person visits. This has proven particularly beneficial during the COVID-19 pandemic, where virtual consultations have enabled continuous monitoring and timely adjustments to treatment plans. Telemedicine interventions have been shown to improve treatment adherence and patient satisfaction, with studies reporting improved glycemic control (measured through HbA1c reduction) and increased patient interaction with their healthcare providers. Furthermore, telemedicine offers cost-saving benefits by reducing the need for frequent hospital visits and improving long-term health outcomes through early interventions.

Wearable technologies, such as continuous glucose monitors (CGMs) and insulin pumps, have revolutionized the approach to diabetes self-management. These devices allow patients to track their glucose levels in real-time and receive automated insulin delivery, improving glycemic control and reducing the frequency of hypoglycemic events. CGMs eliminate the need for multiple daily finger-prick tests, providing users with greater comfort and more comprehensive monitoring. Insulin pumps, when integrated with CGMs, offer a closed-loop system that automates insulin delivery based on continuous glucose readings, reducing the burden of managing insulin injections and improving the patient's quality of life.

Despite these advances, significant challenges remain in the widespread adoption and sustained use of digital health interventions. The digital divide presents a major barrier to access, particularly for older adults, low-income populations, and individuals in rural areas who may lack the necessary digital literacy or resources to utilize these technologies effectively. Moreover, long-term engagement with digital tools can be difficult to maintain, as users often discontinue use after initial interest wanes. This underscores the need for developers to incorporate strategies such as gamification, personalized content, and social support features to enhance user retention.

Additionally, data privacy and security are critical concerns in the adoption of digital health technologies. With increasing reliance on cloud-based data storage and sharing, ensuring compliance with regulations such as the Health Insurance Portability and Accountability Act (HIPAA) and implementing robust

cybersecurity measures are essential to safeguard patient information and foster trust in these technologies.

CONCLUSIONS

Digital health interventions offer significant opportunities to improve the management of diabetes, providing patients with the tools needed to better monitor and control their condition. Mobile health applications enhance self-management by offering real-time feedback and personalized insights, while telemedicine expands access to care, particularly for those in remote and underserved areas. Wearable technologies, such as continuous glucose monitors and insulin pumps, enable real-time tracking and automated insulin delivery, resulting in improved glycemic control and patient satisfaction.

However, the full potential of these digital health tools is yet to be realized. Addressing challenges such as the digital divide, ensuring data privacy, and developing strategies to maintain long-term user engagement are crucial to optimizing their effectiveness. The integration of these digital technologies with traditional healthcare systems and the use of emerging technologies like artificial intelligence for personalized interventions can further enhance diabetes management and patient outcomes. Moving forward, the future of diabetes care will likely rely on a hybrid model that combines the strengths of digital health innovations with traditional care to provide more accessible, efficient, and patient-centered management.

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