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Dr. Mohamed Shafeeq
MD (Internal Medicine), Department of Internal Medicine, Fakeeh University Hospital, Dubai, United Arab Emirates

Dr. Zeeshan Khan
MD, FRCP (Internal Medicine), Department of Internal Medicine, Kings College Hospital, Dubai, United Arab Emirates

Corresponding Author:
Dr. Mohamed Shafeeq
MD (Internal Medicine), Department of Internal Medicine, Fakeeh University Hospital, Dubai, United Arab Emirates

Digital health interventions for diabetes self-management: Harnessing technology for improved outcomes

Dr. Mohamed Shafeeq and Dr. Zeeshan Khan

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Abstract
Diabetes mellitus is a chronic metabolic disorder that affects millions of individuals worldwide. Effective self-management is crucial in controlling the disease and preventing complications. With the advent of digital health technologies, there has been a paradigm shift in diabetes management. This research paper explores the impact of digital health interventions on diabetes self-management and their potential to improve patient outcomes. We review various digital tools and technologies, and present evidence from clinical studies to demonstrate their effectiveness. Furthermore, we will see a new wave of innovations in the area of digital health, smart wearable's, tele-health technologies, and "hospital-at-home" care delivery model. These technologies will be quickly adopted at scale to improve remote management of Diabetes, smartly triaging those who need to be seen in outpatient or inpatient clinics, and supporting acute or subacute care at home. In conclusion, we argue that embracing digital health solutions is essential for enhancing diabetes self-management and ultimately, the quality of life for individuals with diabetes.

Keywords: Diabetes, digital health, self-management, mobile applications, wearable devices, telemedicine, remote monitoring, data security, patient outcomes

1. Introduction
Diabetes mellitus, characterized by persistent hyperglycemia, is a significant global health concern. According to the International Diabetes Federation (IDF), approximately 537 million people were living with diabetes in 2021, with this number expected to rise to 700 million by 2045 if current trends continue. Effective self-management is pivotal in achieving glycemic control and preventing complications such as cardiovascular disease, kidney failure, and retinopathy.

In terms of death and disability, diabetes ranks first globally [1-3]. Glycosylated hemoglobin (HbA1c) less than 7% are therapeutic objectives for glycemic management that unfortunately are not met by the vast majority of patients with diabetes.

Diabetes, if not properly treated, can lead to serious health problems, including heart disease, stroke, nephropathy, retinopathy, and ulcers [5]. The World Health Organization (WHO) reports that diabetes is the ninth greatest cause of mortality globally, accounting for an estimated 1.5 million fatalities each year. In addition, this picture is complicated by diabetic staff shortages [6], restricted public financing, and rising secondary care backlogs, all of which contribute to people with diabetes not getting adequate help.

With diabetes's prevalence only expected to rise, and with no obvious and adaptable solution to the supply side problems faced by healthcare providers, there is a pressing unmet need for accessible, low-cost strategies that can equip and inspire individuals who have diabetes to engage in the most effective forms of diabetes self-care. Self-management has been shown to be an effective method of managing Type 2 diabetes mellitus (T2DM) [7, 8]

Self-management of chronic illnesses [9], especially in the wake of the COVID-19 pandemic [10], has seen a surge in the use of digital health technology (DHTs), such as mobile applications (apps). DHTs have been recommended as cost-effective methods to augment clinician visits and give continuity of care to persons who might have trouble getting incumbent services due to its extensive availability, ease of accessibility, and cheap cost. Individuals with diabetes mellitus now have more options for self-management thanks to the

Availability of technology for purposes such as blood glucose self-management [11], insulin dose and modification [12], and nutritional recommendations [13].

The advent of digital health technologies has ushered in a new era in diabetes care. These technologies encompass a wide range of tools, including mobile apps, wearable devices, remote monitoring systems, and telemedicine platforms. Digital health interventions offer novel opportunities for individuals with diabetes to monitor their condition, make informed decisions, and receive personalized guidance in real-time.

This research paper aims to comprehensively explore the impact of digital health interventions on diabetes self-management.

2. Digital Health Interventions for Diabetes Self-Management

The aim of creating and using digital health technologies is to facilitate the so-called “four purposes” of health care, namely diagnosis, monitoring, treatment, and prevention, leading to four types of outcomes. For diabetes care, the first outcome is increased knowledge of factors affecting diabetes control. Second is support for an individual to move toward a healthier lifestyle that is likely to lead to improved outcomes. Third is support for healthy engagement with a mutually agreed upon treatment regimen so that a person with diabetes will accrue the maximum benefit from this regimen. Fourth is reduction in the personal time burden for self-management

2.1 Mobile Applications

Mobile applications for diabetes management have gained popularity due to their accessibility and versatility. These apps offer features such as glucose tracking, medication reminders, meal planning, and even real-time glucose monitoring through connected devices. More than 318,000 health-related apps were accessible for mobile devices in 2020.Only second to mental health apps in prevalence, diabetes apps made up 16% of the total amount of disease-specific applications available to customers. Some diabetes applications help you keep tabs on your blood sugar levels, while others help you keep track of your carbohydrate intake, your weight, your daily exercise levels, and even your social support network. Patients with diabetes may be more likely to follow their food, exercise, and medication regimens if they are provided with these tools. There has been a rise in the usage of health ("mobile and wireless technologies to support the achievement of health objectives") by healthcare providers, chemists, and patients to aid in diabetes self-management. In most cases, patients may access health via their own mobile devices.

Apps like Glucose Buddy, Diabetes Manager, Dbees, Diabetes Diary and Diabeo Telesage are the most widely used diabetes management apps and their effectiveness in improving glycemic control

2.2 Wearable Devices

Wearable devices, including continuous glucose monitors (CGMs) and insulin pumps, have become integral components of diabetes self-management. They provide real-time data and allow for precise insulin dosing adjustments. The most popular internet-connected diabetic gadgets now include "smart" glucose and blood pressure monitors, activity monitors, and scales. Wearable mini electrocardiographs (ECGs) connected to track cardiovascular health are just one example of the growing number and variety of devices for people living with diabetes, which are expected to revolutionize how the disease is managed. Other examples include "smart" socks, which are intended to observe foot temperature to prevent inflammation and ulcers.

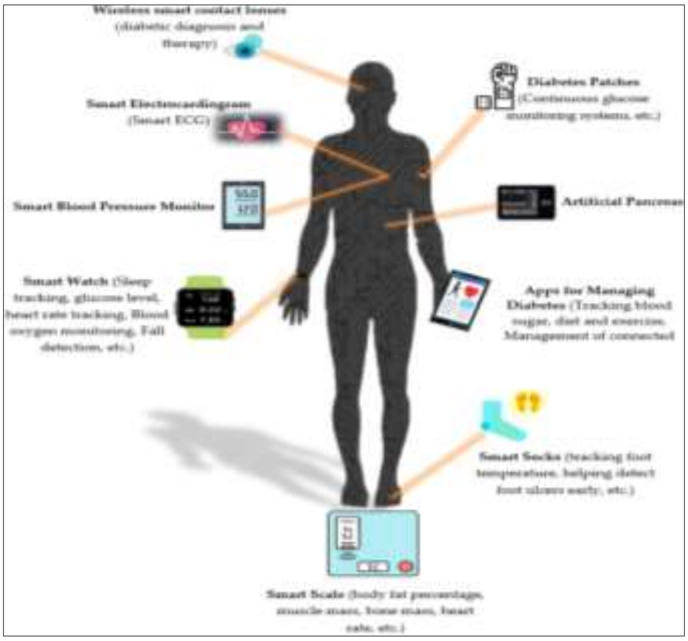

Fig 1: Wearable devices used to support patients with diabetes

Dexcom and Abbott are the manufacturers of two very well-known CGM devices. Abbott makes the FreeStyle, Libre 14 day, FreeStyle Libre 2, and FreeStyle Libre3 systems. FreeStyle Libre 2 and Libre 3 are available for adults and children over 4 years old. The Libre 14 Day system is only for adults 18 years and older.

Dexcom G6 and G7 are what’s known as real time CGM’s. The Dexcom G6 and G7 are currently FDA cleared for adults and children as young as 2 years old. The Dexcom G6 and G7 are currently FDA cleared for adults and children as young as 2 years old.

	Dexcom G6	Dexcom G7	FreeStyle Libre 14 Day	FreeStyle Libre 2	FreeStyle Libre 3
How long does the sensor last?	UP TO 10 DAYS	UP TO 10 DAYS	UP TO 14 DAYS	UP TO 14 DAYS	UP TO 14 DAYS
Time between readings:	5 MINUTES	5 MINUTES	15 MINUTES	1 MINUTE	1 MINUTE
Length of warm-up period:	2 HOURS	30 MINUTES	1 HOUR	1 HOUR	1 HOUR
Low blood sugar alerts?	✓	✓	✗	✓	✓
Smartphone capabilities?	✓	✓	✓	✓	✓
Who can use it?	ADULTS AND CHILDREN 2 YEARS AND OLDER	ADULTS AND CHILDREN 2 YEARS AND OLDER	ADULTS 18 YEARS AND OLDER	ADULTS AND CHILDREN 4 YEARS AND OLDER	ADULTS AND CHILDREN 4 YEARS AND OLDER

Fig 2: Comparison between Dexcom and Freestyle Libre

Eversense from Senseonics is an implantable sensor. A small capsule-shaped sensor is inserted under the skin of the back of the upper arm. This requires a visit to your doctor's office every 90 days to switch the sensor out.

Hypoglycemias are dangerous and measurements of the temperature of the skin and/or conductance of the skin (galvanic skin response) were among the earliest attempts at nocturnal alert systems. These gadgets didn't test blood sugar levels but instead tracked hypoglycemic symptoms like a drop-in body temperature or an increase in sweating. The decrease in skin conductance during hypoglycemia is seen in Figure 1.

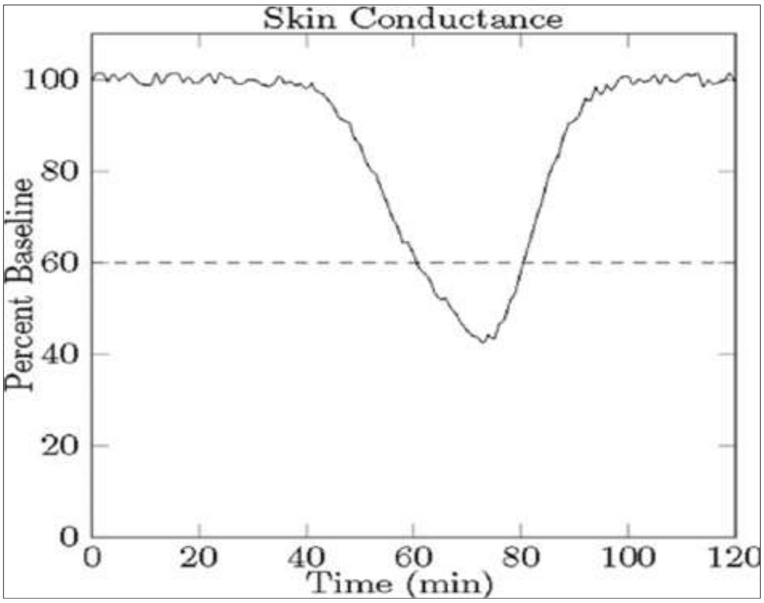

Fig 3: Hypoglycemia's lowest skin conductance point is seen here.

Until now, this technique has only been implemented in the Diabetes Sentry (Diabetes Sentry, Roanoke, TX). The device is designed so that if your body has an increase in perspiration or a decrease in body temperature, your monitor will sound with an alarm to let you know you may be dropping low. The new Sleep Sentry has far better sensors and a more streamlined design than its predecessor. It is in the form of a wrist band. The Sentry alarm has to be verified by testing with a blood glucose monitor. The Sleep Sentry is ideal for those who experience severe or frequent lows, those who live alone with their diabetes, and those who travel frequently.

2.3 Telemedicine and Remote Monitoring

Telemedicine platforms enable healthcare providers to remotely monitor and consult with patients, enhancing access to care and facilitating timely interventions. Remote monitoring devices, such as continuous glucose monitors (CGMs), can provide real-time data on blood glucose levels, allowing healthcare providers to track trends and make timely adjustments to treatment plans. Telemedicine platforms can offer dietary and exercise counseling to help individuals with diabetes make healthier lifestyle choices. Behavioral interventions and support and a timely specialist consultation if needed.

2.4 Data Analytics

Data analytics can integrate data from various sources, including continuous glucose monitors (CGMs), insulin pumps, fitness trackers, electronic health records (EHRs), and patient-reported data. This comprehensive view of the patient's health can provide valuable insights.AI algorithms can then analyse historical data to predict future blood glucose levels. These predictions can help individuals with diabetes make proactive decisions about insulin dosing, diet, and physical activity.

2.5 Diabetic Registries

Guidelines, laws, and policies are no longer based only on the results of randomised clinical trials (RCTs). To complement evidence from randomised controlled trials (RCTs), "real-world evidence" (RWE) can be gathered from other sources such as electronic health records (EHRs), claims from insurance companies, prescription records, social networking sites, and device sensor outputs. One advantage of RWE is that it can collect data on the socioeconomic determinants of health, which have a significant influence on diabetes outcomes, which is often overlooked in randomised controlled trials. There is a wealth of information in registries that may be used to make judgements in the real world. These registries serve several important purposes and offer several benefits in the context of healthcare and diabetes management. Diabetic registries provide valuable epidemiological data about the prevalence, incidence, and distribution of diabetes within a particular population or region. This data helps public health authorities and healthcare providers understand the scope of the diabetes problem and allocate resources accordingly. Registries can also facilitate disease surveillance by tracking diabetes trends over time which can help identify emerging health issues, high-risk populations, and areas where intervention is needed to prevent complications and improve diabetes care. They provide a centralized source of information that allows healthcare providers to track a patient's medical history, treatment plans, and lab results which can ensure that patients receive appropriate and timely care. Risk stratification is an important component, which means identifying individuals at higher risk of complications or poor outcomes based on various factors, including age, comorbidities, and glycemic control.

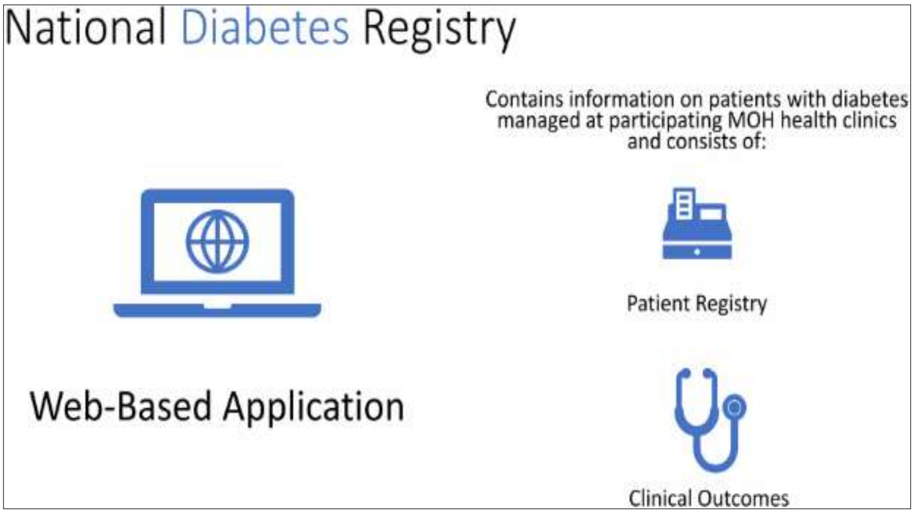

Fig 4: Goal of the Diabetes Technology Registry is to foster confidence, expand patient access, and raise levels of self-efficacy.

2.6 Get Moving Programs

By enhancing glucose homeostasis [15], peripheral blood flow [16], and general health and well-being [17].40 percent of adults with diabetes are physically inactive, doing a maximum of ten minutes of vigorous or moderate exercise per week in the course of their work, leisure, or transportation, despite the widely recognized advantages associated with regular physical activity [18]. The term "exergame" describes the convergence of physical activity with electronic gaming that encourages the user to make use of their muscles while playing. Exergames, the digital gaming adaptation of exercise, are a fun and potentially effective way to get more diabetics moving and keep them moving [19]. For 24 weeks, Höschman *et al.* [20] employed an innovative smartphone game to promote physical activity and exercise in a personalised way for 18 persons with DM2 (mean age 57). The game's narrative was designed to pique players' interest by comparing the player's body to a garden in need of repair and by challenging them to overcome their "Schweinehund," a German idiom for their inferior, lazier selves that is commonly used to refer to their procrastination with regard to PA [20]. Although participants' average daily step count increased by 3998 during the course of the intervention, glycemic control (HbA1c) remained unchanged [20]. But in a previous research [21] of 93 people with IG, using a Wii Fit Plus sports game for 12 weeks, 30 minutes a day enhanced adherence to physical exercise and lowered HbA1c from 7.1% to 6.8%. Therefore, the lack of an improvement in HbA1c in the study by Höschman *et al.* (2019) [20] may have been due to a lack of exercise intensity.

2.7 Remote Nutrition Management/Engagement

Nutrition apps are specifically designed to assist diabetics in making healthy dietary choices which include carbohydrate counting, meal logging, and blood sugar charting and recipe ideas. These apps help users calculate and manage their carbohydrate intake, allowing them to monitor their dietary patterns over time and how different foods affect blood sugar levels. Some offer diabetes-friendly recipes and meal suggestions to inspire balanced and delicious eating.

The Centres for Disease Control and Prevention's Diabetes Prevention Recognition Programme established guidelines in 2015 to validate DPP programmes delivered both in-person and remotely. There were 73 online DPP interventions with either full or provisional CDC recognition as of 3 March 2021 [22]. Most DPP treatments conducted online made use of technology to supply instructional content, digital tracking of individual health data, social support, and feedback from either automated or live health coaches [23].

DPP may be easily and broadly disseminated with the use of text messages sent from a mobile phone. Patients with type 2 diabetes who used mobile and web-based messaging services had their glycated haemoglobin levels drop significantly over the course of a year, as documented by Quinn *et al*. in 2011 [24]. Patients with diabetes were able to log self-care information (such as their blood glucose levels, calorie consumption, and prescription regimens) via the messaging system. Automatic, real-time, data-specific educational, behavioural, and motivational messages were sent back to the patients. Patients with prediabetes who got six text messages per week lost an extra two pounds after 12 months compared to controls [25] in a research by Fischer *et al*. In addition, several research have found that weight reduction is facilitated by texting [26, 27]. Despite the fact that these trials weren't intended to manage diabetes, they do present an enticing intervention because weight loss is so important for preventing diabetes.

While text messaging has shown promise, far more extensive treatments for diabetes prevention can be provided through smartphone and web-based technology. Among 121 people with prediabetes, Michaelides *et al*. [28] compared the effectiveness of the Noom Weight Loss Coach mobile app with human coaching over the course of a 24-week diabetic preventive programme. The Noom Weight Loss Coach is a free app that helps people lose weight by keeping track of their food and exercise habits and offering them proven weight-loss advice and immediate feedback on their progress.

2.8 Technologies to Promote Self-Risk Management

Self-risk management in people with diabetes is taking charge of one's health and making plans to lessen potential dangers. Self-risk management can be improved with the use of technology based on the Internet of Medical Things (IoMT). The term "Internet of Medical Things" is used to describe the connectivity of high-quality medical equipment with built-in communication capabilities and their incorporation into larger-scale health networks. The medical sector is on the verge of a home-care revolution because to recent advancements in cloud data storage, automated tracking, and communication to consumers and healthcare providers.

IoMT has significant potential to enable patients to take charge of their health and advance patients' key role, however applications based on IoMT to treat diabetes are still in their infancy. Already widespread, voice-controlled IoT is expanding to include a wider variety of intelligent personal assistants like Apple's Siri, Amazon's Alexa, Google's Now, and Microsoft's Cortana. These gadgets learn the user's speech so that it can confidently communicate with a variety of programmes. Patient foot checks, glucose monitoring, and weight recording may all be automated with the use of mobile patient portals. In addition, patients or carers can immediately share their findings with their doctors. These rapidly expanding, low-cost, and widely accessible services can assist determine an individual's risk for developing diabetes, diseases, peripheral vascular disease, frailty, and other problems. Despite IoMT's heralding a wave of medical possibilities, difficulties of patient compliance, battery life, and privacy and security have to be resolved.

However, we are at the cusp of a revolutionary shift in health care, one in which the convergence of consumer electronics and healthcare equipment transforms the modern household into the clinic of the future.

Possible Future Uses for EHRs That Make Heavy Use of Digital Data

By standardising APIs, "one-stop shop" marketplaces with turnkey installation may be developed, which in turn will encourage the gathering of aggregated streams of patient and clinician data. Health app development for people with diabetes will be propelled by the availability of huge, sophisticated information housed in an EHR system. FHIR-based "client" apps have been created by major IT firms. Apple, for instance, created the Apple HealthKit retail outlet. HealthKit is the central repository for health and fitness data in iOS, iPadOS, and watchOS. Blue Button 2.0 was also developed by CMS (Centres for Health & Medicaid Services) for American customers. By developing firmware solutions that connect mobile apps directly to the EHR, circumventing the requirement for hospitals to pay possibly expensive ongoing data-bridging services, we anticipate that tiny boutique software businesses will be able to include specialist datasets into the EHR.

Ethical Challenges

Concept of Explain ability

An important factor in recommender systems discourse and an "autonomy-supporting function" in SDT (Muoz and Ramirez 2015) is the concept of explainability (Zhang and Chen 2020), which states that the logic behind an AI or algorithmic procedure should be explained to a user alongside the output. Explainability has become more important in recent years due to the 'black box' nature of some AI approaches. It is possible for machine learning and deep learning models to effectively provide a desired result without explaining the logic behind their decision to do so (Pedreschi *et al*., 2019) [42]. In critical domains like healthcare, where AI-driven searches influence decision-making, accountability is vital. Explain ability helps ensure that AI systems are accountable for their recommendations and actions.

Lack of user control over personal history

Users have historically had complete access to and control over their personal data histories on commercial platforms, with simple options to erase this data at any time. When designing digital health apps, developers should think about whether or not users may remove their data history, or certain segments of it, and how that lack of delete functionality could lead to inappropriate or upsetting suggestions. The user data used by recommender systems is somewhat akin to a patient's medical history

Given the sensitive nature of health data, security and privacy are paramount. Robust encryption, authentication, and compliance with healthcare regulations are crucial. The usage of encryption and blockchain technology are two crucial components that might make a system based on IoMT more secure.

There are four fundamental ethical concerns that must be resolved before AI in healthcare can reach its full potential. It's crucial to think about [1] getting people's permission before using their data, [2] keeping them secure and transparent, [3] avoiding bias in algorithms, and [4] protecting their personal information.

Conclusion

Providing people with diabetes with the resources they need to effectively manage their illness, interventions in digital health have a chance to usher in a new era of diabetic self-management. The effectiveness of diabetic self-management digital health treatments depends on using a patient-centered approach. These emerging technologies have the potential to revolutionize the healthcare industry. With the use of these tools, patients may become active participants in their own treatment. More crucially, technological progress may allow for a shift in the care delivery model, from viewing the patient just as a recipient of treatment to viewing the patient as an active participant in the health community.

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