WEARABLE TECHNOLOGY FOR THE MANAGEMENT OF DIABETES

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Abstract
The prevalence of diabetes mellitus is rising daily. A major global health concern that affects hundreds of millions of people globally is diabetes mellitus. Each year, diabetes claims the lives of several million people. Dynamic, real-time glucose monitoring is essential for both effective treatment and preventing problems. With an emphasis on cutting-edge developments and their incorporation with artificial intelligence (AI), this review offers a thorough summary of the quickly changing field of wearable technology for glucose monitoring and diabetes treatment. We examine various methods of glucose monitoring, such as smart watches and continuous glucose monitors (CGMs), emphasizing how they help with direct glucose readings, food consumption, medication adherence and physical activity tracking. In the future, wearable technology will revolutionize diabetes care by improving diabetes detection and treatment.

Keywords: diabetes, global health, artificial intelligence, wearable technology, glucose monitoring, smart watches

Introduction
Diabetes is a long-term condition that impairs the body's capacity to control blood sugar levels. Changes in lifestyle, medication adherence, and routine monitoring are necessary for effective management [1,2].Conventional techniques, such keeping diaries and performing fingerstick blood tests, can be time-consuming and could not give a complete picture of a patient's health [3]. Wearable technology is becoming a vital component of diabetes care. Users can measure their blood sugar levels, physical activity, food, and medication use in real time via continuous glucose monitors (CGMs), insulin pumps, fitness trackers, and smart watches. These gadgets help patients make better decisions, give immediate feedback, and let medical professionals watch patients remotely [4,5]. By examining data trends to forecast glucose variations and provide personalized recommendations, the incorporation of artificial intelligence (AI) into these wearables increases their usefulness [6,7]. In addition to increasing treatment results, this proactive strategy assists patients in better managing their illness [8,9]. Nonetheless, maintaining data accuracy, resolving privacy issues, and facilitating universal access to these devices continue to be major obstacles [10].

Type 1 Diabetes Mellitus (T1DM)
T1DM is an autoimmune disease where the immune system targets the pancreatic cells that produce insulin. This leads to a complete lack of insulin. Children and young people are frequently diagnosed with it, and lifetime insulin therapy is necessary. To enhance glycemic control and lessen problems like diabetic ketoacidosis, wearable technology like CGMs and hybrid closed-loop insulin pumps are frequently utilized [11].

Epidemiology
About 5–10% of all instances of diabetes worldwide are T1DM, and its incidence is rising by almost 3% a year, particularly in children under the age of 15 [2]. While Asia and South America exhibit lower incidence rates, Northern Europe has the highest rates [12].

Symptoms:
- Polyuria (frequent urination)
- Polydipsia (excessive thirst)
- Polyphagia (increased hunger)
- Unexplained weight loss
- Fatigue
- Diabetic ketoacidosis (DKA) at onset (vomiting, abdominal pain, fruity-smelling breath, rapid breathing)
- Sometimes blurred vision [11,12]

Management
It is important to get continuous subcutaneous insulin infusion (CSII) or multiple daily injections (MDI) for the duration of one's life [13,14].Hybrid closed-loop systems with continuous glucose monitoring (CGM) enhance glycemic results and lower the risk of hypoglycemia [15,16].Additionally important are lifestyle changes, education, psychological support, and problem-spotting [17, 18].

Type 2 Diabetes Mellitus (T2DM)
Insulin resistance and a steady decrease in insulin production are hallmarks of type 2 diabetes. It is the most prevalent type of diabetes and is associated with lifestyle choices like obesity and sedentary behavior [19].Dietary changes, physical activity, and drugs like SGLT2 inhibitors and

metformin are all part of management.Wearables are useful for measuring exercise, monitoring blood sugar, and enhancing patient compliance [20].

Epidemiology

T2DM is the most common type of diabetes, accounting for over 90% of all cases globally [3,4].Because of dietary changes toward foods high in energy, urbanization, and a decline in physical activity, its incidence is rising quickly worldwide, especially in low- and middle-income nations.Age over 45, obesity, a family history of diabetes, a sedentary lifestyle, and metabolic syndrome are major risk factors [21].

Symptoms:

- Often gradual onset; may remain asymptomatic for years
- Polyuria (frequent urination)
- Polydipsia (excessive thirst)
- Fatigue
- Blurred vision
- Recurrent infections (skin, urinary tract)
- Slow-healing wounds
- Sometimes acanthosis nigricans (darkened patches of skin, usually neck or armpits) [19]

Management

The most common kind of diabetes is type 2 diabetes, accounting for almost 90% of all cases globally [3,4].Its incidence is rising quickly worldwide, especially in low- and middle-income nations, primarily as a result of dietary changes toward foods high in calories, urbanization, and decreased physical exercise.Significant risk factors include being older than 45, being obese, having a family history of diabetes, leading a sedentary lifestyle, and having metabolic syndrome [21].

Gestational Diabetes Mellitus (GDM)

Hormonal alterations that affect insulin action during pregnancy cause GDM [25].It raises the risk of problems for both mother and child, even though it is frequently asymptomatic.Diet, exercise, and glucose monitoring are the main objectives of management.To evaluate continued diabetes risk, postpartum follow-up is crucial [26].

Epidemiology

Approximately 16.7% of pregnancies worldwide experience hyperglycemia during pregnancy, with GDM accounting for the majority of these cases [27].Ethnicity, maternal age, obesity, and diagnostic criteria all have a substantial impact on prevalence. Due to variations in screening and testing methods, pooled prevalence estimates in Europe vary from 2% to 20%.The lifetime risk of type 2 diabetes is 7–10 times higher for women with GDM, and their children are more likely to be obese and have poorer glucose tolerance in later life [27].

Symptoms:

- Frequently asymptomatic; detected during routine pregnancy screening
- Possible symptoms: polyuria, polydipsia, fatigue, recurrent infections
- Risk factors: maternal obesity, advanced age, family history of diabetes, prior macrosomic infant, PCOS [25,26]

Management

Modifying one's lifestyle to include a balanced diet, controlling weight, and engaging in moderate physical activity is the cornerstone of managing GDM. There is substantial evidence to support the usefulness of medical nutrition therapy, especially low glycemic index meals. Continuous glucose monitoring devices (CGMs) or self-monitoring of blood glucose should be used to keep an eye on glucose control [25, 26].Insulin is regarded as the gold standard pharmaceutical treatment if lifestyle changes are not enough, while metformin and glyburide may be taken into consideration in certain situations. In order to detect chronic diabetes or prediabetes, women should have a 75-g oral glucose tolerance test (OGTT) 6–12 weeks after giving birth. Postpartum care is crucial.[27]

Table 1: Types of Diabetes Mellitus

Type	Causes / Pathophysiology	Key Features	Management
Type 1 Diabetes Mellitus (T1DM)	Autoimmune destruction of pancreatic β-cells → absolute insulin deficiency	Sudden onset, more common in children/young adults, lean body type, ketosis prone	Lifelong insulin therapy, diet, lifestyle modification
Type 2 Diabetes Mellitus (T2DM)	Insulin resistance + relative insulin deficiency; linked with obesity, aging, and genetics	Most common (>90%), gradual onset, usually adults, overweight/obese, strong family history	Lifestyle changes (diet, exercise), oral hypoglycemic drugs, insulin if needed
Gestational Diabetes Mellitus (GDM)	Pregnancy hormones cause insulin resistance; usually appears in 2nd–3rd trimester	Temporary during pregnancy, increases risk of complications for mother and baby; higher risk of future T2DM	Diet, exercise, insulin (if needed), postpartum follow-up
Other Specific Types	Genetic mutations , neonatal diabetes); secondary to diseases (pancreatitis, Cushing's), or drugs (glucocorticoids)	Rare, variable onset, often misdiagnosed	Tailored therapy (may not always need insulin), treat underlying condition

Wearable Medical Devices:

Portable, body-worn tools intended to track, document, or modify health-related parameters in real time are known as wearable medical devices. These devices are becoming more and more significant in today's healthcare system [28] because they facilitate ongoing patient monitoring, early anomaly detection and better chronic condition treatment,. In order to give patients and healthcare professionals actionable data, wearables combine sensors, wireless connection, and frequently cloud platforms or mobile apps. They fall within the larger heading of digital health technology, which also includes remote monitoring systems, mobile health apps, and telemedicine. The main benefit of wearable technology is that, unlike traditional episodic measurements made in clinical settings, it may give longitudinal, personalized, and real-time health data [29, 30].

Wearable medical devices monitor health parameters in real time, enabling early detection and management of chronic conditions [31].Types include:

- Physiological Monitors (heart rate, BP, respiration)
- Biochemical/Metabolic Monitors (glucose, lactate)
- Activity and Motion Trackers
- Smart Clothing/Textiles
- Wearable Imaging/Diagnostics
- Emerging Devices (microneedle patches, smart contact lenses) [32,33]

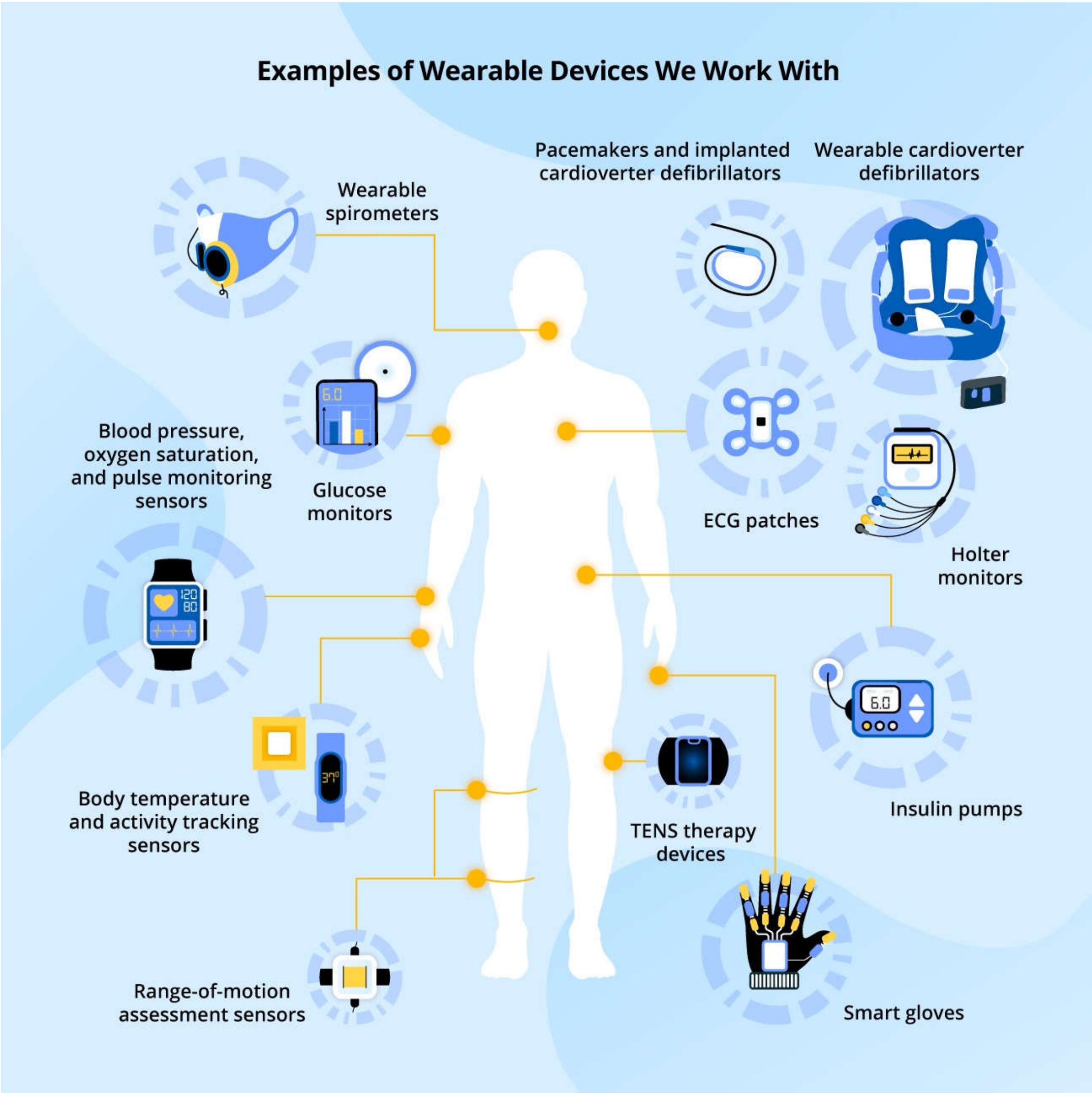

Figure: 1 Wearable Medical Devices

Depending on their purpose and objective criteria, wearable medical devices come in a variety of forms.Vital indicators like heart rate, blood pressure, respiration rate, oxygen saturation, and body temperature are measured by physiological monitors employing sensors such as photoplethysmography (PPG), electrocardiography (ECG), piezoelectric, and optical sensors.These devices are frequently used in sleep research, heart monitoring, and tracking overall fitness.They provide ongoing, non-invasive monitoring that enables the early identification of anomalies, albeit motion artifacts and battery life restrictions may compromise their accuracy.The Fitbit, Apple Watch (ECG), and Zephyr BioPatch are typical examples.

Biomarkers including glucose, lactate, electrolytes, or sweat metabolites are detected and measured by biochemical and metabolic monitors. To measure analytes, these devices usually use optical detection techniques, enzymatic processes, or electrochemical sensors. They are used in metabolic tracking, glucose monitoring, and hydration evaluation. These wearables allow for real-time decision-making and provide biochemical data without the need for intrusive blood samples, but they also need sensor calibration and are susceptible to interference from the environment. Sweat biosensors and continuous glucose monitors like Dexcom and Abbott Libre are two examples.

Activity and motion trackers use accelerometers, gyroscopes, and magnetometers to record movement, steps, posture, balance, and the intensity of physical activity. They are helpful in gait analysis, fitness tracking, rehabilitation, and identifying falls among the elderly. Although they occasionally need to be calibrated and may not correctly record subtle motor movements, their non-invasiveness, real-time feedback, and capacity to enhance adherence to workout regimens make them valuable. ActiGraph, Xiaomi Mi Band, and Garmin Vivosmart are notable examples.

Smart textiles and apparel use strain sensors, textile electrodes, and conductive fibers to incorporate sensors into textiles to track physiological data. These clothes are appropriate for continuous heart monitoring, posture correction, and sports performance evaluation since they can detect cardiac signals, respiration, or muscle action. Though there are drawbacks, such as cost, durability, and washing restrictions, smart clothing is comfortable, discrete, and appropriate for long-term monitoring. Hexoskin smart shirts and Sensoria socks are two examples.

Wearable imaging and diagnostic devices incorporate miniaturized cameras, ultrasound probes, or optical scanners into wearable form factors to capture images or diagnostic signals. These gadgets are employed for retinal imaging, gastrointestinal monitoring, skin lesion evaluation, and wound monitoring. Their field-of-view, resolution, and privacy issues may restrict their use, but they enable remote diagnostics and patient-centered monitoring. Wearable endoscopic capsules and smart patches with optical sensors are two examples.

Lastly, a new class of gadgets investigating non-invasive monitoring of biomarkers, brain activity, or medication delivery are developing and experimental wearables. Examples include smart contact lenses that measure intraocular pressure or glucose, electronic tattoos that track sweat composition, hydration, or ECG, and microneedle patches for transdermal drug administration or glucose sensing. Although the majority of these devices are still in the research stage, their accuracy, longevity, and regulatory approval are being assessed. Nevertheless, they are patient-friendly, minimally invasive, and provide continuous monitoring.

The advantages of wearable medical devices include continuous, real-time monitoring of physiological and biochemical parameters, early detection of health abnormalities, increased patient engagement, and adherence to treatment or lifestyle interventions. Clinicians can monitor patients remotely thanks to integration with mobile health platforms. Notwithstanding these advantages, there are still issues, such as sensor accuracy that is impacted by motion and ambient factors, cybersecurity and data privacy issues brought on by wireless data transfer, device accessibility and cost, battery life restrictions, and regulatory barriers to clinical approval. [28, 32, 34].

Wearable Medical Devices in Diabetes Management

Diabetes mellitus (DM) is one of the most prevalent chronic diseases worldwide, characterized by persistent hyperglycemia due to impaired insulin secretion, insulin resistance, or both. Over 500 million persons worldwide presently have diabetes, and that number is predicted to increase dramatically over the next several decades, according to the International Diabetes Federation.Diabetes must be managed with lifelong blood glucose monitoring, medication compliance, lifestyle changes, and ongoing medical care. Conventional techniques, such finger-stick tests for self-monitoring of blood glucose (SMBG), have drawbacks, including being uncomfortable, sporadic, and unable to measure glucose variations.

In recent years, wearable medical devices have revolutionized diabetes care by providing continuous, real-time monitoring and, in some cases, automated therapeutic interventions. These devices enhance patient autonomy, improve adherence, and support clinicians with objective data for decision-making .

TYPES OF WEARABLE DEVICES IN DIABETES MANAGEMENT

Continuous Glucose Monitoring (CGM) Systems

One of the most revolutionary wearable technologies in the treatment of diabetes is the CGM.These devices detect interstitial glucose levels frequently (every 1–5 minutes) using a tiny subcutaneous sensor [4,5].Wireless transmission of data to a smartphone, smartwatch, or dedicated receiver is used.In addition to real-time glucose readings, contemporary CGMs include trend data, hypoglycemia and hyperglycemia alerts, and data exchange with caregivers.In comparison to SMBG, several clinical trials show that CGMs significantly lower the risk of hypoglycemia, improve time-in-range, and lower glycated hemoglobin (HbA1c).Medtronic Guardian Connect, Abbott FreeStyle Libre, and Dexcom G6/G7 are popular CGM devices [35, 36].

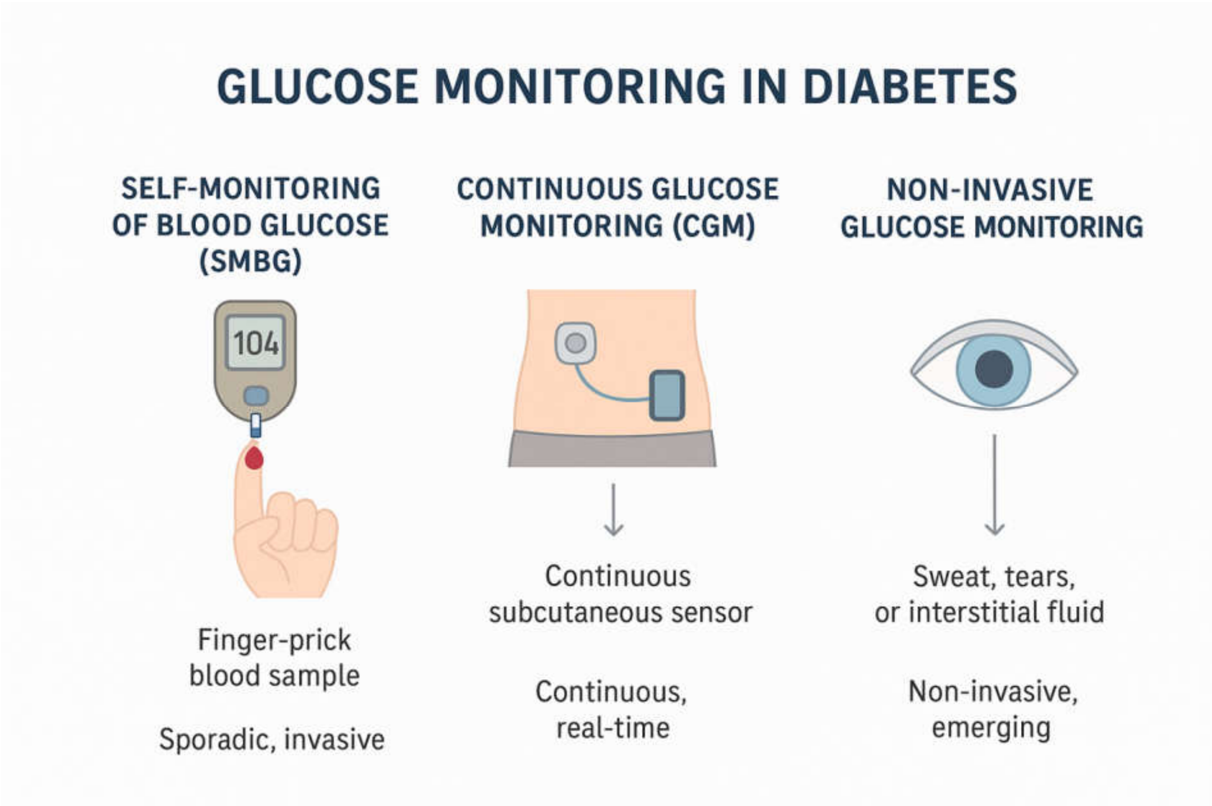

Figure: 2 Continuous Glucose Monitoring (CGM) Systems

Insulin Pumps (Continuous Subcutaneous Insulin Infusion – CSII)
Rapid-acting insulin is administered via insulin pumps via a subcutaneous catheter. They enable bolus dosing prior to meals and offer continuous basal insulin delivery. Insulin pumps provide more flexibility, better glycemic control, and a decreased risk of hypoglycemia when compared to several daily injections. Moreover, hybrid closed-loop systems that incorporate pumps and CGMs lay the groundwork for "artificial pancreas" technology. Tandem t: thin X2 and Medtronic MiniMed 770G are well-known examples [37].

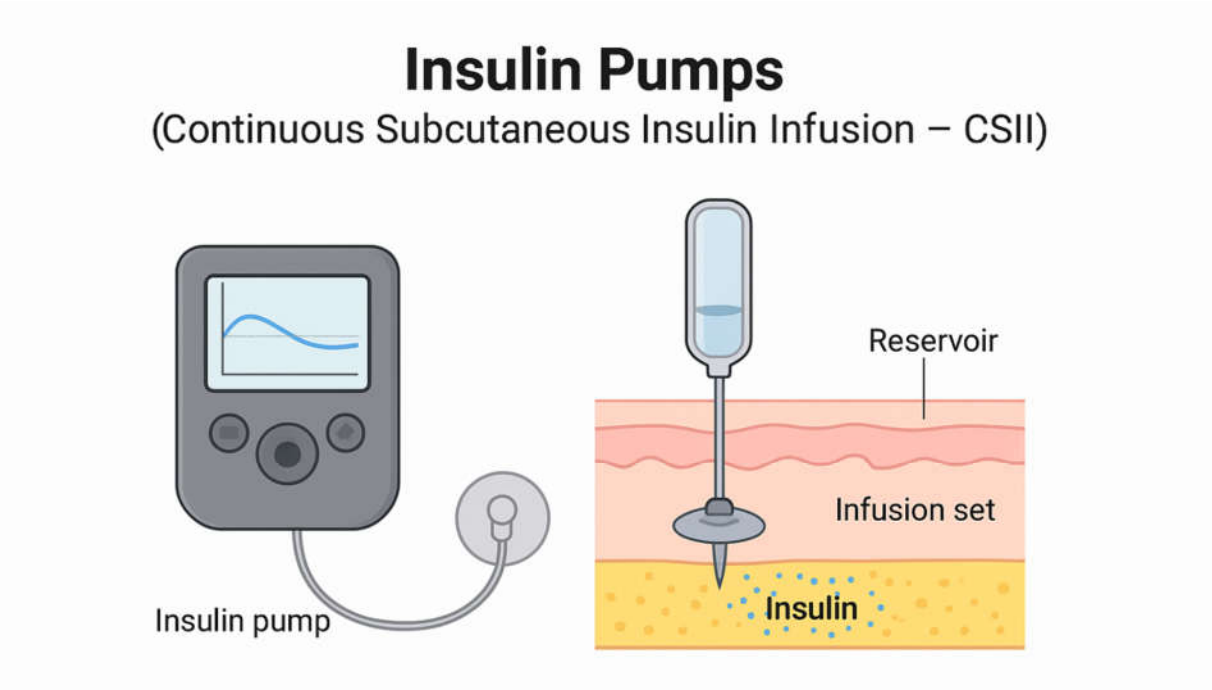

Figure:3 Insulin Pumps (Continuous Subcutaneous Insulin Infusion)

Smart Insulin Pens and Patch Pumps

Digital technology is used in smart insulin pens to calculate suggested dosages, record dosing history, and sync data to smartphone apps.They aid in lowering missing or inaccurate dosages, which frequently stand in the way of efficient glycemic management.The Omnipod Dash and other patch pumps are tiny, tubeless devices that stick to the skin and administer insulin without the use of external tubing.A larger population can utilize these devices since they are more user-friendly and less expensive than conventional insulin pumps [38].

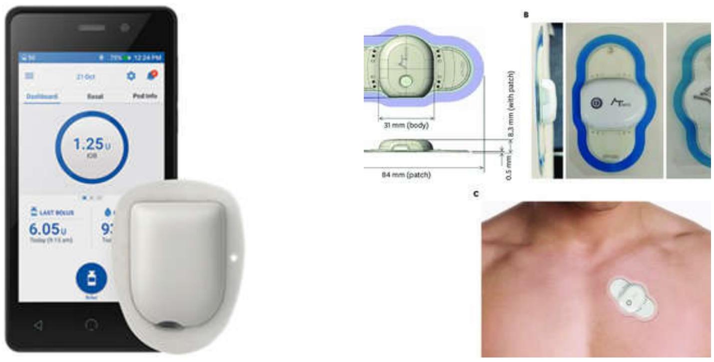

Figure:4 Smart Insulin Pens and Patch Pumps

Closed-Loop (Artificial Pancreas) Systems

Closed-loop systems use sophisticated control algorithms to combine insulin pump supply with CGM data. The device mimics physiological insulin regulation by automatically modifying insulin delivery in response to real-time glucose readings. According to clinical research, closed-loop devices considerably lessen the strain of managing diabetes, enhance HbA1c, and decrease glycemic fluctuation [39]. While completely automated "bionic pancreas" devices are in advanced clinical trials, current systems like the Medtronic 780G reflect hybrid closed-loop models.

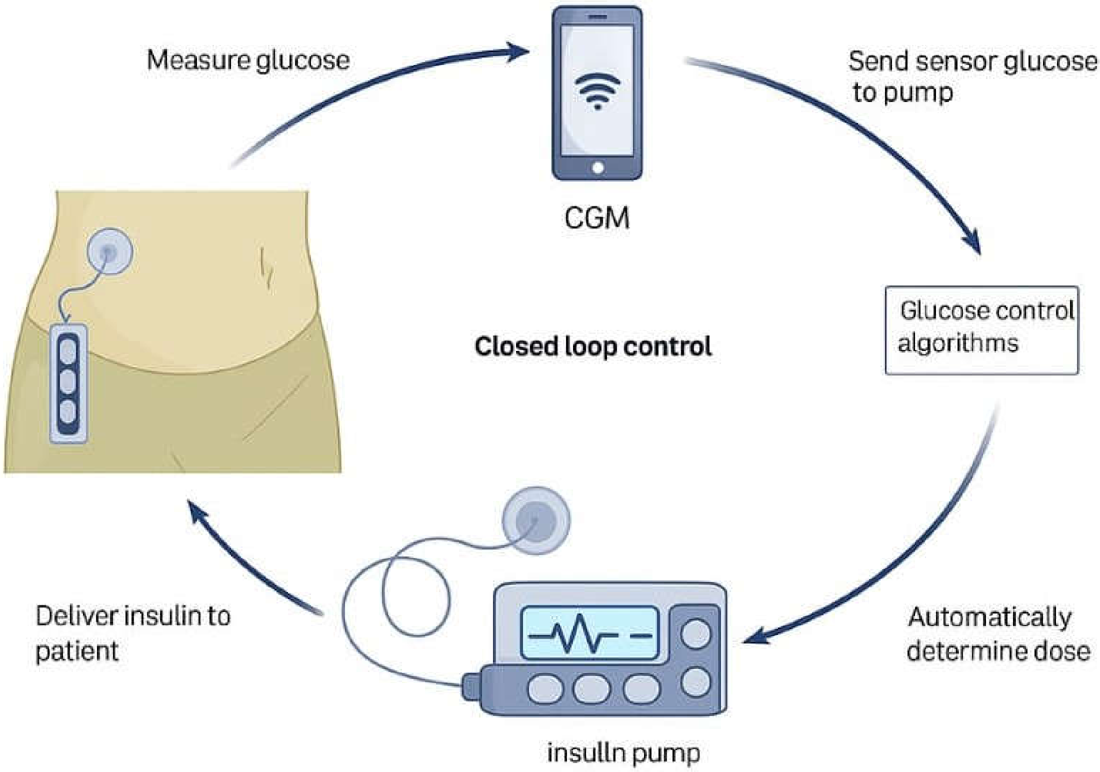

Figure :4 Closed-Loop (Artificial Pancreas) Systems

Smartwatches and Fitness Trackers

Despite not being specifically made for diabetes, wearable technology like as Fitbit and the Apple Watch are very helpful. They offer ongoing tracking of calorie expenditure, heart rate, sleep patterns, and physical activity [24,33].They provide convenience and real-time decision support by directly displaying glucose levels on the smartwatch when coupled with CGM platforms.

Figure:6 Smartwatch

Emerging and Experimental Wearables
The use of diabetic wearables is growing as a result of creative research. Sweat-based glucose biosensors, smart contact lenses, and microneedle patches are examples of experimental devices that allow for non-invasive or minimally invasive glucose monitoring. These technologies are the future of painless, individualized diabetic management, even though they are not yet generally accessible [39, 40].

Advantages and Challenges of Wearable Devices
Wearable technologies offer numerous benefits including continuous data collection, reduced patient burden, prevention of complications, and enhanced patient engagement. Problems with device calibration, data privacy, high cost, and restricted availability in low-income areas still exist, though. For broad acceptance, these restrictions must be addressed.[41]

Table 2: Types of devices

Device Type	Function	Advantages
Continuous Glucose Monitors (CGMs)	Measures interstitial glucose continuously (every 1–5 min) and sends data to phone/watch	Real-time glucose monitoring- Alerts for hypo/hyperglycemia- Improves HbA1c & time-in-range- Data sharing with caregivers
Insulin Pumps (CSII)	Delivers insulin continuously (basal) + bolus doses at meals	Mimics physiological insulin release- Reduces hypoglycemia- Greater flexibility than injections
Smart Insulin Pens	Records insulin dose/time, calculates recommended bolus, syncs with apps	Affordable vs pumps- Tracks missed doses- Easy integration with CGM apps
Patch Pumps	Tubeless, adhesive device delivering insulin subcutaneously	Small, discreet, no tubing- User-friendly- Convenient for children & active patients
Closed-Loop Systems (Artificial Pancreas)	Integrates CGM + pump + algorithm to adjust insulin automatically	Best glycemic control- Reduces patient burden- Decreases complications risk
Smartwatches & Fitness Trackers	Track activity, heart rate, sleep; some integrate CGM data	Lifestyle monitoring- Real-time display of glucose when paired- Motivates physical activity
Emerging Devices	Non-invasive glucose sensing via sweat, tears, microneedles, smart tattoos	Painless monitoring- Potentially low-cost in future- High patient acceptance

Glucose Monitoring in Diabetes:

In order to maintain optimal glycemic control, lower the risk of acute complications like hypoglycemia and hyperglycemia, and avoid long-term complications like nephropathy, retinopathy, neuropathy, and cardiovascular disease, glucose monitoring is an essential part of diabetes management. In addition to monitoring blood glucose levels, maintaining glycemic control necessitates recognizing patterns and trends over time, which are frequently missed by conventional techniques like self-monitoring blood glucose (SMBG).

Self-Monitoring of Blood Glucose (SMBG) has been the mainstay of glucose monitoring for decades. To get precise glucose levels, patients use glucometers to do finger-prick capillary blood sample. SMBG is affordable, accessible, and easy to use. Nevertheless, it only offers sporadic blood glucose readings, which may not capture notable variations or instances of hypoglycemia or hyperglycemia. Furthermore, frequent finger pricking can cause discomfort and decrease patient compliance, which limits its ability to provide the best possible glycemic control.

The development of Continuous Glucose Monitoring (CGM) has revolutionized diabetes care by offering real-time, dynamic insight into glucose levels. Every one to five minutes, CGM systems monitor interstitial glucose using tiny subcutaneous sensors and wirelessly send the results to a receiver, smartphone, or smartwatch [42].Real-time CGM (rtCGM) and intermittently scanned CGM (isCGM, often called flash glucose monitoring) are the two main categories of CGM devices. While isCGM needs the patient to scan the sensor in order to observe glucose levels, real-time CGM continually gives glucose readings along with warnings for hypo- or hyperglycemia. Clinical research shows that CGM lowers the risk of hypoglycemia, minimizes glycemic variability, considerably lowers HbA1c levels, and gives trend data and prediction warnings for proactive treatment, especially in patients with type 1 diabetes. The Abbott FreeStyle Libre for isCGM and the Dexcom G6/G7 for rtCGM are well-known CGM devices. Notwithstanding these benefits, CGM sensors can be costly, need to be changed on a regular basis (usually every 7–14 days), cause some minor discomfort when inserted, and have a tiny lag between blood glucose and interstitial measurements. The goal of newly developed minimally invasive and non-invasive glucose monitoring systems is to increase patient compliance and convenience. Experimental smart contact lenses assess glucose in tear fluid, microneedle patches painlessly sample interstitial fluid, and sweat-based sensors detect glucose electrochemically in perspiration. The majority of these inventions are still in research or early clinical trials, and before they are widely adopted, their accuracy and reliability must be confirmed. Nevertheless, they promise continuous monitoring without the need for conventional finger pricks.

There are numerous clinical benefits of wearable glucose monitoring. Better glycemic control and the detection of patterns that could otherwise go overlooked are made possible by continuous real-time data. Closed-loop systems that automate insulin delivery based on glucose measurements are made possible by integration with insulin pumps and smartphones. Furthermore, wearable technology makes it easier for medical professionals to monitor patients remotely, which enhances patient involvement and treatment compliance. There are still issues, though, such as the high cost of the device, its limited accessibility in environments with limited resources, the possibility of interference affecting the accuracy of the sensor (temperature, pressure, or physical activity), worries about data privacy and cyber security, and the requirement for patient training to guarantee proper use and calibration.

Future advancements in glucose monitoring are probably going to concentrate on continuous, accurate, and non-invasive sensors that work well with wearable technology and digital health platforms. By predicting hyperglycemia excursions and recommending tailored therapies, developments in artificial intelligence and predictive analytics may improve glucose management even more. In the end, wearable glucose monitoring in conjunction with telemedicine and customized diabetes care may greatly enhance patient outcomes and lessen the costs of diabetes-related medical care. [43].

Wearable Devices in Diabetes Management: Enhancing Physical Health

Predictive analytics and artificial intelligence developments could improve glucose management even more by predicting diabetic excursions and recommending tailored therapies. In the end, telemedicine, individualized diabetes treatment, and wearable glucose monitoring may greatly enhance patient outcomes and lessen the costs of diabetes-related medical care. [43]

Continuous glucose monitors (CGMs), insulin pumps, smart watches, biosensors, and other gadgets that check blood sugar, physical activity, sleep patterns, and other pertinent health indicators are all included in the broad category of wearable technology. With the potential to improve metabolic control, patient involvement, and general quality of life, these devices have become indispensable in the treatment of diabetes.

One of the most popular wearable technologies for managing diabetes is the CGM. They monitor the amount of glucose in the interstitial fluid using a tiny sensor that is subcutaneously placed, usually on the arm or belly. Real-time data transmission to a smartphone or receiver enables patients and medical professionals to track patterns and modify treatment as necessary. Frequent fingerstick testing is less necessary with CGMs, which also assist in identifying hyperglycemia and hypoglycemia before clinical symptoms manifest. Improved sensor accuracy, extended wear times, and integration with smartphone apps that offer trend analysis and alarms are some recent developments in CGM technology. To further improve safety and glycemic control, several devices now have predictive algorithms that can alert users to approaching hypoglycemia.

Insulin Pumps and Automated Delivery Systems

Insulin pumps replicate endogenous pancreatic function by continuously delivering insulin subcutaneously with a programmable catheter. These pumps can be used with CGMs to create closed-loop "artificial pancreas" systems that automatically modify insulin dosage in response to real-time glucose measurements. Glycemic variability, HbA1c levels, and the incidence of hypoglycemic episodes are all decreased by this automation.Unlike several daily injections, wearable insulin pumps offer flexibility and convenience by enabling precise dosage throughout meals and physical activities. Patient satisfaction and adherence have been further enhanced via mobile app integration and user-friendly interfaces.

Smartwatches and Fitness Trackers

Although primarily designed for general health monitoring, smartwatches and fitness trackers have valuable applications in diabetes care. These gadgets can track physical activity, heart rate, and sleep patterns, giving information that affects glycemic management. They help patients make better decisions by allowing them to link lifestyle choices with changes in blood sugar levels through syncing with diabetes management applications.[45]Non-invasive glucose monitoring is being investigated via new wristwatch technologies, however the precision of these methods is still being studied. However, they have the ability to enhance patient engagement and offer real-time feedback.

Wearable Biosensors

Insulin biosensors and wearable electrochemical glucose sensors provide continuous monitoring without the need for frequent fingersticks. They can offer immediate feedback on insulin levels and glucose patterns, which eases the strain of conventional monitoring and enhances everyday self-management. Those with type 1 diabetes who need strict glucose control would particularly benefit from these sensors [46].

BENEFITS OF WEARABLE DEVICES IN DIABETES MANAGEMENT

Improved Glycemic Control

Wearable technology has been shown in numerous studies to enhance glycemic management in people with type 1 and type 2 diabetes. Early detection of glucose excursions made possible by CGMs and automated insulin delivery devices enables prompt therapies that lower HbA1c and hypoglycemic episodes.Constant input improves overall illness management by enabling patients to make quick lifestyle changes.

Enhanced Patient Engagement and Adherence

Wearable devices encourage patient engagement by providing visual data, trend alerts, and reminders. This increased awareness promotes adherence to prescribed treatment regimens and supports proactive self-management. Patients report higher satisfaction and confidence when using wearable technology, which translates to improved health outcomes[47].

Personalized Treatment Plans

Healthcare professionals may customize treatment programs to meet the needs of each patient thanks to the vast datasets produced by wearable technology. The efficacy of therapies is increased by providing tailored suggestions for dietary, exercise, and medication modifications through the analysis of glucose patterns, insulin administration, activity levels, and sleep metrics.

Data Accuracy and Reliability

Although wearable devices offer many benefits, accuracy remains a concern, particularly for non-invasive sensors. Regulatory agencies, including the FDA, caution against using unapproved devices claiming to measure glucose without clinical validation, as inaccuracies can lead to serious health risks[48].

Cost and Accessibility

The high cost of wearable devices and limited insurance coverage pose barriers to widespread adoption.Access disparities may prevent some patients from benefiting from advanced monitoring technologies, particularly in low-income or rural settings.

Data Privacy and Security

Wearable devices collect sensitive health information, raising privacy and cybersecurity concerns. It is essential to ensure that patient data are securely transmitted and stored and that patients understand how their information is used.

Future Directions

The integration of artificial intelligence (AI) and machine learning (ML) with wearable devices holds great promise for diabetes management. AI can predict glucose trends, optimize insulin dosing, and provide personalized recommendations. Future wearable technologies may offer fully automated glucose control, improved patient engagement, and better integration with electronic health records, facilitating comprehensive diabetes care.

Direct Glucose Monitoring:

Technologies that assess glucose levels in people with diabetes in real-time or intermittently are referred to as "direct glucose monitoring." These technologies have several advantages over conventional fingerstick testing. The most popular of these are continuous glucose monitors, or CGMs. CGMs assess the amount of glucose in the interstitial fluid using a tiny subcutaneous sensor that is usually placed on the upper arm or belly. The sensor continuously sends data to a receiver, smartphone, or smartwatch. A hybrid closed-loop system that automatically modifies insulin delivery in response to glucose measurements can be created by integrating advanced CGMs with insulin pumps. Trend arrows, hypo- and hyperglycemia warnings, and predictive alerts are some of the features that these devices provide. These features allow for prompt treatments, lower glycemic fluctuation, and enhance diabetes care in general.

Another approach, flash glucose monitoring (FGM), exemplified by the Free Style Libre system, and involves a sensor that must be scanned manually by the user to obtain glucose readings. While FGMs do not provide real-time alerts, they still allow patients and clinicians to monitor glucose trends over time, improve glycemic control, reduce the frequency of fingerstick tests, and enhance patient adherence [48].

Emerging non-invasive glucose monitoring technologies aim to measure glucose without skin penetration, using techniques such as optical sensors, spectroscopy, or biosensors in sweat or tears. The majority of the devices are still in the research or early commercial stages, and while these techniques have the potential to provide painless, needle-free monitoring, their accuracy and dependability are currently restricted. Because of the possible health concerns, regulatory bodies, such as the FDA, advise against using unapproved devices that purport to test blood glucose without invasive sensors.[49]

Overall, direct glucose monitoring technologies have had a transformative impact on diabetes care. CGMs and FGMs provide actionable data that help reduce HbA1c levels, prevent hypoglycemia, and improve patient engagement. These devices facilitate informed decision-making for patients and healthcare providers by providing real-time or almost real-time glucose feedback, allowing for tailored treatment modifications. Even though non-invasive glucose monitoring is still in its experimental stage, more research is anticipated to increase its precision and broaden its application in the treatment of diabetes soon [50].

Artificial Intelligence in Wearable Medical Devices for Diabetes

Artificial intelligence (AI) is increasingly being integrated into wearable medical devices to enhance diabetes management. Large amounts of real-time data from gadgets like insulin pumps, smartwatches, and continuous glucose monitors (CGMs) can be processed by AI algorithms to produce tailored suggestions and predictive insights. By going beyond conventional reactive methods, this integration enables more proactive and accurate diabetic care. Predictive glucose management is one of the most important uses of AI in wearable technology. Artificial intelligence (AI) models can forecast imminent hyperglycemia or hypoglycemia by examining glucose patterns, insulin supply, physical activity, and dietary inputs. Because of its predictive ability, the gadget can notify patients before harmful glucose excursions happen,

allowing for prompt actions. In hybrid closed-loop systems, AI can automatically adjust insulin delivery based on these predictions, effectively functioning as an "artificial pancreas" and improving glycemic control while reducing the risk of hypoglycemia.
Additionally, AI is being utilized to customize diabetic treatment regimens. Wearable technology continuously gathers information about heart rate, blood sugar, physical activity, and sleep habits. These statistics are analyzed by AI algorithms to produce personalized insights, such as the best times to eat, the best insulin dosages, or modifications to exercise regimens. Patient involvement, adherence, and general quality of life can all be enhanced by this individualized approach.
Wearables with AI capabilities facilitate behavioral interventions in addition to glucose control. Devices can identify patterns of inactivity or irregular sleep, for instance, and offer personalized coaching or reminders to promote better habits. By combining AI with real-time monitoring, diabetes management may be approached holistically, taking into account lifestyle and metabolic aspects.
There are still difficulties in spite of these developments. High-quality data is essential for AI systems; predictions may be jeopardized by imprecise sensor readings or missing data. Furthermore, as AI systems handle sensitive health data, data security and privacy are important issues. To guarantee that AI-enabled devices handle patient data in a way that is safe, efficient, and transparent, regulatory frameworks are changing. In summary, the use of AI in wearable medical technology is revolutionizing the way diabetes is managed. AI-powered devices offer the potential to enhance glycemic outcomes, lower complications, and give patients more control over their disease by facilitating behavioral support, tailored therapies, and predictive glucose control. Maximizing the advantages of AI in diabetes management will require ongoing clinical validation and increased accessibility as technology develops.[51]

DEVICES FOR FOOD AND MEDICATION MONITORING IN DIABETES

Food Monitoring Devices

Accurate dietary monitoring is crucial for effective diabetes management. Patients can make real-time dietary adjustments by using continuous glucose monitoring (CGM) systems to connect glucose trends with meals. CGMs decrease glucose fluctuation, enhance glycemic control, and issue alerts for hyperglycemia and hypoglycemia. On-demand glucose readings are provided by flash glucose monitoring devices, such Freestyle Libre, which can assist patients in understanding how their diet influences their blood sugar levels. Furthermore, wearable food trackers and mobile health applications (mHealth apps) can record meals, calculate calories and macronutrients, and interface with CGMs, improving patient involvement and promoting improved dietary management [24].

Medication Monitoring Devices

Proper medication adherence is essential for optimal glycemic control. Smart insulin pens assist reduce missed doses and avoid insulin stacking by recording the kind, timing, and dose of insulin injected, sending reminders, and providing data to healthcare providers. In addition to helping patients manage complicated prescription schedules, electronic pill dispensers and reminder devices enable clinicians to remotely check adherence when connected with cloud platforms or mobile apps. Combining glucose and meal tracking with medication monitoring offers a comprehensive strategy for individualized diabetes care. [33, 52].

The future of diabetes management lies in seamless, non-invasive glucose monitoring combined with AI-powered analytics. Efforts should focus on:

- Developing affordable and accessible devices.
- Improving sensor accuracy and calibration.
- Addressing data privacy through robust encryption and user education.
- Expanding research into wearable technologies integrated with personalized treatment algorithms.

Collaboration between engineers, clinicians and policymakers is essential to ensure that these technologies reach all segments of the population. Working together, these stakeholders can drive innovation, enhance patient care, and make advanced diabetes management solutions widely available and effective.

Conclusion:

There is early potential in using wearable and mobile technologies to monitor diabetes-related indicators. Everyone should be able to wear high-tech gadgets without experiencing any discomfort, ideally. Wearable technology, such as watches, belts, shoes, and glasses, should be used to assess blood pressure, heart rate, blood glucose levels, physical activity, and energy intake and consumption in people with diabetes in a free-living environment. Additionally, the development of wearable technology for diabetes care will heavily rely on artificial intelligence. Blood glucose control, blood glucose prediction, adverse glycemic event detection, insulin bolus calculators, meal and exercise detection, and lifestyle assistance for diabetes management are all examples of artificial intelligence techniques that have grown in importance. In future, artificial intelligence in combination with wearable devices will enhance personalized diabetes management. So, its development can benefit patients with diabetes, health care professionals and researchers.

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