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Review Article

Diabetic technology in India: Status, barriers, and future prospects

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ABSTRACT

This article provides a comprehensive review of diabetic technology in India. Researchers are persistently integrating novel technologies and enhanced medical knowledge to offer further avenues for improving the well-being of individuals with diabetes. Continuous patient engagement is essential by using highly effective technologies that address pertinent issues, as certain problems can be resolved with precision. India has a demographically large population, characterized by a substantial segment of individuals with diabetes. The estimated prevalence of diabetes in India is approximately 8%, with type 2 diabetes accounting for half of these occurrences. India's per capita expenditure on health constantly falls behind that of other developing countries. Refined statistical data indicate that India's healthcare expenditure is <50% of the average expenditure observed in the Organization for Economic Co-operation and Development (OECD) countries.

Keywords: diabetes; patient management; blood glucose; state of art; global scenario; Indian scenario

1. Introduction

The field of diabetes research in India has made significant progress over the years. The nation currently exhibits a diabetic population of more than 120 million individuals, with projections indicating a substantial increase to surpass 300 million by 2030. Based on data provided by the International Diabetes Federation, it is evident that the prevalence of diabetes in India is 7.4%, a figure that surpasses the global norm by approximately twofold.

In the context of India, the management of diabetes can be achieved through the implementation of dietary modifications and engagement in regular physical activity. However, many individuals encounter challenges in adhering to medication schedules and comprehending the therapeutic benefits of their prescribed drugs. Consequently, the use of continuous glucose monitors is of considerable significance for individuals diagnosed with diabetes in India. These devices assist in monitoring blood glucose levels throughout the day and ensuring a continuous supply of insulin to prevent depletion prior to its required administration.

In a survey encompassing 9581 adult participants (**Figure 1**) between the ages of 18 and 69, it was found that 9.3% exhibited elevated blood glucose levels, which included individuals using medication. Among this group, 45.8% were cognizant of their elevated blood glucose status. Among those who were aware of their

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condition, 78.8% were receiving treatment for elevated blood glucose levels, and within this subgroup, 32.7% had effectively managed their blood glucose levels, as evidenced by fasting blood glucose levels below 126 mg/dl.

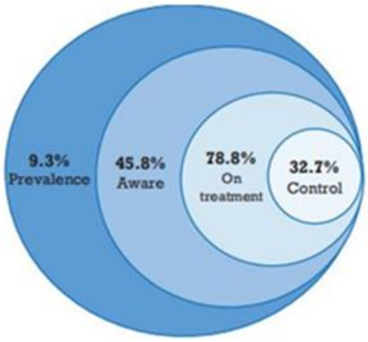

Figure 1. Assessment of the management of diabetes mellitus among adults (18–69 years).
Source: National Noncommunicable Disease Monitoring Survey (NNMS) 2017–18.

Individuals diagnosed with type 1 diabetes may be required to provide daily insulin injections within the confines of their own residence, whereas alternative treatment modalities such as insulin pumps may be employed by others. Individuals diagnosed with type 2 diabetes are advised to engage in regular physical activity and adhere to a nutritious dietary regimen that includes whole grains, vegetables, and fruits. Continuous glucose monitors (CGMs) are valuable instruments for patients with diabetes to effectively monitor their blood glucose levels throughout the day. If a healthcare professional has recommended the use of such devices, they can facilitate the more precise monitoring of glucose levels compared with the manual process of pricking one's own skin for blood samples at regular intervals throughout the day. Continuous glucose monitoring devices are used to monitor blood sugar levels in patients diagnosed with diabetes. In addition to discerning elevated, diminished, and standard levels, these measurements can provide insights into the efficacy of insulin therapy. The implementation of the device necessitates the insertion of a diminutive sensor beneath the dermal layer. The sensor is designed to periodically assess blood glucose levels at 5-min intervals and transmit the collected data to a glucose monitor via wireless communication. The monitor then presents the information on one of the three available screens, categorized as type 1 diabetes, type 2 diabetes, or pre-diabetes.

The prevalence of diabetes in India is increasing. Over the course of the previous two decades, there has been a notable surge of 64% in the prevalence of diabetes among the Indian populace, resulting in a current affliction rate surpassing 16% of the total population. The incidence of type 2 diabetes exhibited a notably elevated rate among the female population, with a prevalence of 30%. Moreover, those of Nigerian descent face the highest susceptibility to the development of this ailment. The mean age of diabetes onset in India has exhibited an upward trend, increasing from 37 years in 1990 to 39 years in 2020 (**Figure 2**). This implies that individuals in younger age groups may face a higher level of vulnerability than those in previous generations, namely, their parents and grandparents.

The causes behind this rise remain incompletely understood, while certain scholars posit a potential association with lifestyle modifications encompassing a sedentary existence, excessive body weight or adiposity, heightened stress levels, and insufficient engagement in physical exertion. Nevertheless, the etiology of diabetes is multifactorial, involving a complex interplay of genetic predisposition and environmental influences, including dietary patterns and lifestyle choices, which gradually impact metabolic processes. The healthcare system in India lacks the necessary resources and infrastructure to effectively address the challenges posed by diabetes and its associated ailments. One of the primary challenges encountered by diabetic individuals in India pertains to a dearth of knowledge among patients and their families, coupled with limited financial resources and inadequate availability of high-quality healthcare services.

Several organizations are actively involved in enhancing diabetes awareness in India, such as the World Health Organization (WHO), International Diabetes Federation (IDF), and Diabetes Association of India (DAI). However, these organizations have encountered challenges in delivering adequate assistance to individuals afflicted by diabetes.

One potential solution to address this situation involves enhancing doctors' knowledge about diabetes and its associated complications through ongoing educational initiatives, such as webinars or conferences. These platforms facilitate interaction between doctors and experts in the field, including international physicians and researchers engaged in collaborative diabetes research projects in India.

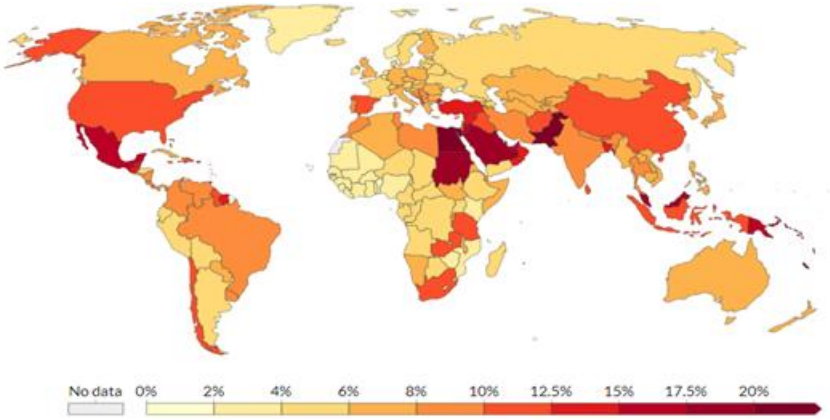

Figure 2. Diabetes prevalence refers to the percentage of people aged 20–79 years with type 1 or type 2 diabetes. Source: International Diabetes Federation (via World Bank).

General diabetes statistics

- Approximately 537 million people between 20 and 79 years of age live with the disease, or 10.5% of the global population;
- It is estimated that by 2045, global diabetes prevalence will surpass 12%;
- It is expected that the number of people with this condition will increase by 134% in Africa, 68% in Southeast Asia, and 13% in Europe.

The structure of this paper is as follows:

Section 2 provides a detailed discussion of the different technologies available in the West, along with their respective features and limitations. Section 3 provides information about different apps for diabetic care. In section 4, we present our research work, i.e., the development of a prototype glove for diabetic reversal and management. Because of the flexible nature of polyimide, we used it as a substrate. Finally, section 6 concludes the text with a conclusion and future work.

2. Diabetic technology in western countries

2.1. Diabetic monitors

2.1.1. Big foot unity

Big foot unity (see **Figure 3**) is designed to work as a real-time partner in the management of diabetes. The system continuously monitors glucose levels and displays information regarding the amount of insulin to be taken. The Big Foot Unity caps provide access to insulin doses recommended by the healthcare provider.

The black cap represents the long-acting insulin dose. It tracks the last time it recorded a dose of insulin and displays the long-acting insulin dose. The Big Foot unity app can also let the user know when they have missed long-acting insulin. The white cap is for the rapid-acting insulin pen. It reminds the user of the last time a dose of insulin was recorded. Big Foot unity comes with a FreeStyle Libre sensor to continuously monitor glucose levels. When the sensor is scanned, the white cap uses glucose information to help determine information such as meals and corrections. The best feature is that the Bigfoot Unity app connects to all these devices and tracks insulin and glucose history. It can also alert when the glucose level is low or very low.

Figure 3. Big Foot Unity system (Source: Businesswire & Date: 10 May 2021).

2.1.2. InPen

InPen (see **Figure 4**) is a device that allows precise and accurate insulin delivery in individuals with diabetes. The InPen is an intelligent insulin pen designed to administer mealtime insulin. The device possesses a long-lasting battery. The cartridges have a capacity of 300 units of insulin. One advantage of using InPen is its ability to monitor insulin age, as its efficacy may diminish after 30 days. This device can establish a Bluetooth connection with a mobile application, facilitating the execution of all necessary insulin administration computations.

Figure 4. InPen (Source: Medgadget & Date: 2 August 2016).

2.1.3. OmniPod

OmniPod (see **Figure 5**) is a medical device that falls under the category of wearable insulin pumps. It is designed to provide continuous subcutaneous The Omnipod is a tubeless automated insulin delivery system that is capable of being submerged in water. It seamlessly integrates with the Dexcom G6 and Omnipod 5 apps, featuring a smart bonus calculator. This system provides regular reports of blood glucose levels to the pod at 5-min intervals.

Figure 5. Omnipod 5 (Source: Heathline & Date: 31 January 2022).

2.1.4. Freestyle Libre

The Freestyle Libre (see **Figure 6**) is a flash monitoring system that requires the user to scan the sensor using a reader or mobile phone to access real-time glucose data displayed on the device's screen. There are three categories of alarms that can be configured to notify elevated, reduced, or intermediate glucose levels. The user can customize the alarm levels to suit their preferences, allowing them to proactively respond to the alarms. The sole constraint lies in the requirement for scanning to be consistently performed to initiate data transfer from the sensor to the device, as the sensor is programed to retain data for a maximum duration of eight hours. The receiving device shall retain the data for a maximum period of 90 days. These limitations are addressed in FreeStyle Libre 3, where scanning is facilitated through NFC, the same technology employed in Apple Pay or contactless credit cards.

Figure 6. Freestyle Libre 2.

2.1.5. Eversense

The Eversense Continuous Glucose Monitor (CGM) (see **Figure 7**) is professionally inserted every 90 days at the physician's clinic. The sensor can be implanted subcutaneously in the brachium, while a wearable transmitter is externally positioned. The duration of this sensor's presence within the body is 90 days. Traditionally, the replacement interval for the other sensors is 7 to 14 days. Numerous patients have reported its convenience.

Figure 7. Eversense.

2.1.6. CeQur

The CeQur Insulin patch (see **Figure 8**) can contain a maximum of 200 units. To administer insulin, the user simply needs to click on the side of the patch.

Figure 8. CeQur simplicity.

2.2. Diabetic Care Apps worldwide

Figure 9 depicts some of the most recent efforts in this field of diabetes care.

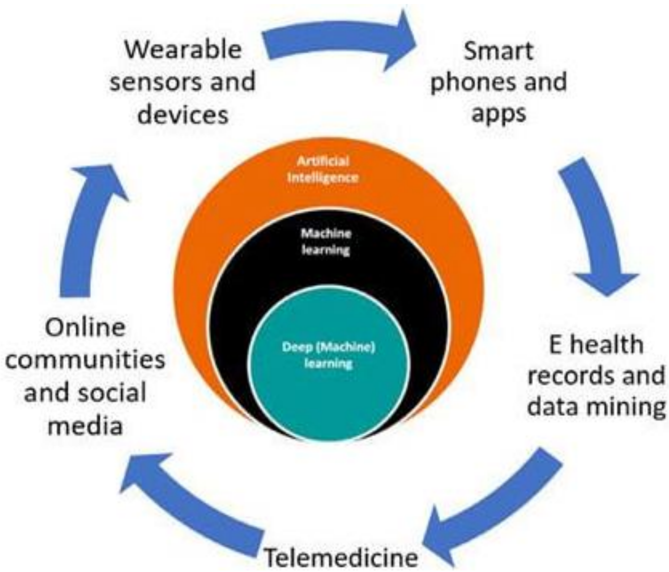

Figure 9. Applications of artificial intelligence in diabetes care[1].

Tools to help care for people with diabetes include apps that support patient management and research and tools that allow patients to monitor their own health. Recent advances in diabetes care have been remarkable. A patient can self-monitor and reduce the number of visits to the doctor. There are some incredible possibilities in using apps for patients with diabetes. Here is a list of apps you should know about.

2.2.1. EyeApp

EyeApp, a smartphone-based end-to-end point-of-care diabetic retinopathy diagnostic device, will truly enable diabetic retinopathy screening at a massive scale, which is necessary and urgent because the world's diabetic population is estimated to be a staggering 371 million and is projected to grow to over half a billion by 2030. EyeApp uses an image sensor designed specifically for vision testing and advanced algorithms that help detect diabetic retinopathy (DRS) while improving patient interactions with their care team. This new technology reduces cost, enhances convenience and ease of use, boosts job satisfaction, and provides timely diagnosis of DRS.

2.2.2. App for knowing the adverse effect of metformin

Healthline's Bezzy T2D is a safe space for people living with diabetes and those who are close to them to connect, discuss, learn, and share how they can improve their lives with the help of medication and lifestyle changes.

2.2.3. Notes in the endocrinology app

Notes in Endocrinology are digitalized notes written by Dr. Om J. Lakhani. Notes contain valuable guidance on all aspects of endocrinology. This study is an attempt to digitize the Notes written by Dr. Om J Lakhani in the field of endocrinology on topics such as diabetes mellitus, insulin and its use, hypoglycemia and its pathological changes, and treatment thereof. In this presentation, a special focus is on diabetes mellitus (DM), the third leading cause of death worldwide.

2.2.4. Glokoo

Glooko improves the health outcomes of people with chronic conditions through the power of our global, personalized, and intelligent connected care platform. Glooko is a global technology company focused on improving the health of people with chronic conditions and empowering providers. They develop and market next-generation platform technologies that bring together health and wellness organizations and people across multiple stages of life, with a focus on diabetes. Their integrated suite of cloud applications enables frictionless care delivery, personalized, intelligent, connected care, and patient engagement and adherence through digital therapeutics.

2.2.5. Leveraging data and digitization in diabetic management: India

The ICMR-INDIAB study (**Figure 10**), run by the Indian Council of Medical Research (ICMR), was all about checking how common metabolic non-communicable diseases (NCDs) like diabetes and heart issues are across India. They looked at data from 15 different states. There is a big difference in how many people have these conditions depending on where they live. This huge study helps researchers identify the depth of the problem and shows where more health support might be needed to tackle these diseases.

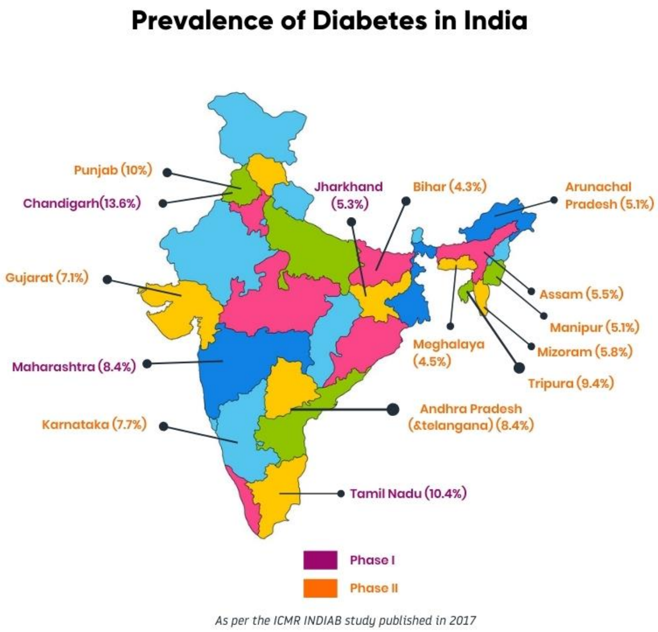

Figure 10. Indian clusters.

Source: Prevalence of Diabetes in India.

Based on the study using the huge database called the Indian Council of Medical Research–India Diabetes (ICMR–INDIAB) study and using k-clustering, the Indian population is divided into 4 clusters[2]. The rapidly expanding diabetes population in India has put tremendous strain on the nation's healthcare system. The trajectory of digital health in diabetes is changing as a result of the convergence of several cutting-edge and developing technologies. For the prevention and management of diabetes, the diabetes community has been embracing various technologies, including SMBC, CGM, continuous subcutaneous insulin infusion, closed-loop systems, digitalization of health data, and diabetes-related mobile apps.

2.3. Antenna design for noninvasive glucose monitoring

Table 1 summarizes the prior work done in wearable antennas.

Table 1. Literature review.

Reference	Year	Authors	Work Done
[3]	2021	Umar et al.	Proposed unified fabric antennas capable of communication with a subcutaneously implanted sensor
[4]	2021	Khajeh-Khalili et al.	Proposed novel wearable wideband antenna and used denim as antenna substrate
[5]	2020	Alqadami et al.	Proposed a conformal compact, low-profile, and unidirectional antenna.
[6]	2020	Pei et al.	Proposed a dual-band belt antenna based on the pin buckle belt for body communication networks.
[7]	2020	Guangchen et al.	Proposed low-profile conformal antenna for WBAN
[8]	2020	El Gharbi et al.	Developed flexible antenna sensors for the detection of sweat and temperature.
[9]	2020	Joshi et al.	Used synthetic fibers polymers as antenna substrate
[10]	2019	SärestöNiemi et al.	The antenna is used as a sensor for the human chest
[11]	2020	Kannagi et al.	The antenna is used as a sensor for anaemia detection
[12]	2019	Ding et al.	Proposed an implantable rectenna for biomedical application

Table 1. (*Continued*).

Reference	Year	Authors	Work Done
[13]	2018	Yousefnia et al.	The antenna is used as a sensor for breast cancer detection
[14]	2018	Das et al.	The design and analysis of a compact and flexible implantable slot antenna are addressed is done in this paper
[15]	2017	Hu et al.	The antenna is used as a sensor for human body radiation patterns
[16]	2017	Lee et al.	Proposed a wearable antenna integrated into a military beret to achieve an indoor/outdoor positioning system.
[17]	2019	Hasan et al.	Proposed the cole-cole blood glucose model.
[18]	2018	Jang et al.	Designed a split-ring resonator-based Glucose sensor
[19]	2018	Sethi et al.	Designed an elliptical DR sensor that was less sensitive to thumb positioning than the elliptical patch sensor.
[20]	2017	Turgul and Kale	Simulations were performed using a 4-layer fingertip model and a unique fingerprint imprinted model.
[21]	2020	Masihi et al.	Designed and developed a tunable patch antenna using rapid prototyping techniques
[22]	2020	Abutarboush et al.	Designed and developed a flexible and wideband antenna, which can be fabricated using a low-cost screen-printing technique.

In recent years, there has been a significant emphasis on biomedical research endeavors aimed at the creation and advancement of flexible and wearable medical devices. These devices were specifically designed to cater to the needs of disease detection, early intervention, preventive measures, and continuous health monitoring. Health monitoring is a crucial application that enables the acquisition of vital signals without causing any disruption to a patient's regular activities. To ensure the fulfillment of this requirement, it is imperative to emphasize the significance of utilizing an antenna as a sensor for monitoring the patient's daily routine. The study, as described by Bharadwaj et al.[23], aimed to investigate the propagation characteristics of an antenna when placed at different locations on the human body. In addition, this study explores the various factors that can affect the accuracy of measurements within a wireless body sensor network. To facilitate body-centric wireless communications, it is imperative to thoroughly examine the transmission properties of the dual-polarized armband textile antenna array, along with supplementary sensors, across different regions of the human body[24]. Epidermal antennas, which are positioned atop the skin, have gained significant popularity in recent times.

Problems with Noninvasive Diabetic measurement:

Non-invasive diabetic measurement refers to the use of techniques that do not require penetration of the skin to monitor blood glucose levels in individuals with diabetes. This approach offers several advantages over traditional invasive methods, such as finger pricking, including reduced pain and discomfort and decreased risk of infection. In this study, saliva samples were collected for non-invasive glucose monitoring[25]. To develop an accurate and cost-effective continuous glucose monitoring device, researchers have employed a novel approach that uses a nanosensor capable of measuring salivary biochemistry on a disposable basis. This innovative technology holds great promise for revolutionizing glucose monitoring and offers a convenient and affordable solution for individuals managing diabetes. By harnessing the potential of this nanosensor, researchers can enhance the quality of life of patients while simultaneously reducing the economic burden associated with glucose monitoring. This study involved the participation of two healthy adult individuals who underwent a series of eight noninvasive experiments. Each experiment lasted for 2–3 h and involved the consumption of both regular food and standard glucose beverages. In each experimental trial, 35 saliva samples were collected for analysis. The present study investigates the limitations associated with a particular method employed in previous research. Specifically, the method under scrutiny was found to exhibit several drawbacks, including the presence of numerous impurities within the sample. Consequently, these impurities led to a diminished correlation between variables, reduced sensitivity in detecting target analytes, and inadvertent proliferation of bacterial organisms.

Tear glucose analysis has emerged as a crucial alternative method for indirectly, conveniently, and non-invasively measuring blood glucose levels[26]. The widespread adoption of tear glucose analyzers for glucose monitoring is hindered by several factors, including high costs, complexity, and low comfort levels. In addition, the need to replace the sensor after each analysis in disposable testing further limits the use of tear glucose analyzers. In this study, the use of a nanogold electrode material, as described previously[27], was investigated for the development of a sweat sensor aimed at glucose monitoring. The production of sweat is primarily attributed to the eccrine glands, which secrete a complex composition of substances, including ions, metabolites, acids, small proteins, and peptides. One notable drawback associated with the use of this particular technique is the necessity of perspiration during each analysis. In a study by Chen et al.[28], a novel approach for noninvasive intravascular glucose monitoring was introduced. The proposed method uses skin-like biosensors to achieve accurate and reliable glucose measurements. This innovative technique has the potential to revolutionize glucose monitoring by offering a noninvasive alternative to traditional invasive methods. By leveraging the unique properties of skin-like biosensors, researchers aim to overcome the limitations associated with current glucose monitoring techniques, such as discomfort and the risk of infection. The findings presented by Saha et al.[29] provide valuable insights into the feasibility of the proposed technology. The present study introduces a novel technology comprising an ultrathin, skin-like biosensor integrated with electrochemical twin channelspowered by paper batteries (ETCs). Nevertheless, the current methodology has been observed to induce skin irritation.

Related work:

In this section, we review the existing literature and research relevant to our study. The purpose of this review is to provide a comprehensive understanding of the current state of knowledge in Non-invasive diabetes measurement devices that have emerged in the market, offering a promising alternative to traditional invasive methods. These devices provide accurate and convenient glucose monitoring without the need for frequent finger pricks or blood samples. This article explores the current landscape of non-invasive diabetes measurement devices, highlighting their potential benefits and limitations. By examining the available options, individuals with diabetes can make informed decisions about incorporating these devices into their self-management. The detection of blood glucose levels using invasive methods has gained significant acceptance and practicality in various healthcare settings, including hospitals and home glucose meters. Introduction Biochemical analyzers are essential tools used in hospitals to measure various biochemical parameters in patient samples. One such parameter of great clinical significance is blood glucose levels. Accurate measurement of blood glucose levels is crucial for diagnosing and monitoring conditions such as diabetes mellitus. In this study, we focused on the use of a biochemical analyzer to measure blood glucose levels in individuals who undergo blood sampling in the early morning. This study involved the collection of blood samples from individuals in a hospital setting. The participants were instructed to fast overnight and refrain from consuming any food or beverages, except water, prior to blood sampling. Blood samples were obtained using standard injection techniques, ensuring minimal discomfort to the participants. The collected samples were then immediately transferred to a biochemical analyzer for analysis. The biochemical analyzer used in this study demonstrated high precision and accuracy in measuring blood glucose levels. The instrument employed an enzyme. The precision of the obtained results and their diagnostic capability for diabetes are noteworthy. However, the current methodology presents certain limitations that hinder its suitability for continuous monitoring of individuals with diabetes. These limitations include the lengthy process involved in conducting the diagnostic test, the considerable time required for detection, and the substantial volume of venous blood required for the procedure. Consequently, alternative approaches may need to be explored to address these challenges and enable more efficient and convenient monitoring of diabetic patients. The classification of continuous glucose monitoring methods encompasses two main categories: invasive and non-invasive techniques. These methods are employed to continuously monitor glucose levels, providing valuable insights into an individual's glycemic control.

The categorization of these monitoring approaches aids in understanding their distinct characteristics and applications within the field of glucose monitoring. Skin-safe glucose sensors have emerged as a promising non-invasive approach for monitoring glucose levels in individuals. These sensors offer a convenient and painless alternative to traditional invasive methods, such as finger pricking. By using advanced technology, these sensors are designed to be placed on the surface of the skin, allowing for continuous glucose monitoring without causing any harm or discomfort to the user. In addition to skin-safe sensors, minimally invasive glucose sensors can be placed on the top of the stomach or upper arm. These sensors require slight insertion into the skin, but the procedure is relatively simple and causes minimal discomfort. By strategically placing the sensors in these locations, individuals can effectively monitor their glucose levels while minimizing the invasiveness of the monitoring process. Both non-invasive and minimally invasive glucose sensors play a crucial role in the field of glucose monitoring. Anticipated advancements in the field of non-invasive continuous glucose monitoring (CGM) technology are projected to yield a substantial increase in the market availability of such devices by 2030. Introduction Wearable sensors have gained significant attention recently because of their potential applications in various fields, including healthcare, sports, and human– computer interaction. These sensors typically require the application of a patch to the skin, allowing the collection of physiological data. However, the current model of wearable sensors involves the insertion of a sensor filament with a diameter of less than 0.4 mm directly into the skin. This novel approach presents unique advantages and challenges that will be explored in this research article. The insertion of a sensor filament into the skin offers several advantages over the traditional patch-based approach. First, this method eliminates the need for adhesive patches, which can cause discomfort and skin irritation in some individuals. By directly inserting the filament into the skin, the sensor can establish a more reliable and stable connection, ensuring accurate data collection. Furthermore, the small diameter of the sensor filament allows for minimally invasive insertion, thereby reducing the risk of tissue damage and potential infection. This is particularly beneficial for long-term monitoring applications, where the sensor remains in contact with the skin for extended periods. The reduced invasiveness also enhances user comfort, enabling seamless integration of the wearable sensor into daily activities. Challenges and Considerations While the insertion of a sensor filament into the skin presents numerous advantages, it also introduces certain challenges that must be addressed. One primary concern is the potential for discomfort or pain during insertion. Careful design and engineering of one such continuous glucose monitoring device is the Abbott Freestyle Libre sensor, which is widely used by patients with type 1 diabetes. The use of non-invasive and skin-safe sensors has gained significant preference in the monitoring of glucose levels.

The aforementioned technologies offer either continuous or intermittent readings, akin to the existing Continuous Glucose Monitoring (CGM) systems, with the latter necessitating patient engagement. Wearable glucose sensors have gained significant attention as a promising alternative to the conventional "finger pricking" monitoring method. This traditional approach often involves invasive blood collection, which can be accompanied by pain and stress. In contrast, wearable glucose sensors offer a non-invasive solution, thereby mitigating the discomfort associated with blood collection. The field of non-invasive blood glucose monitoring has gained significant attention worldwide as a prominent area of research and a potentially effective treatment approach for individuals with diabetes. This innovative method holds great promise for improving the lives of numerous diabetic patients. The presence of glucose is observed in various bodily fluids, including intracellular fluids, interstitial fluids (ISF), tears, saliva, and urine (1). These fluids serve as important sources for the detection and measurement of glucose levels in the body. Understanding the distribution of glucose across these bodily fluids can provide valuable insights into the physiological processes and metabolic regulation associated with glucose metabolism. Measurement of blood glucose levels has emerged as the predominant diagnostic tool for the identification of diabetes mellitus. According to a recent market analysis, the worldwide market for continuous glucose monitoring systems (CGMS) is projected to attain a substantial valuation of $8844.9 million within the period spanning from 2019 to 2027. The GlucoWISE® system is a cutting-edge, noninvasive, and painless testing method that employs near-infrared spectroscopy (NIR) technology. NIR spectroscopy is a powerful analytical technique that uses the interaction between light and matter to provide valuable insights into the composition and properties of various substances. In the context of GlucoWISE®, NIR spectroscopy is used to measure and analyze glucose levels in a non-invasive manner, eliminating the need for traditional invasive blood sampling methods. This innovative approach holds great promise. The GlucoWISE® device is designed to measure attenuation that occurs after the passage of light through the skin. In light of the aforementioned considerations, it is imperative to optimize the wavelength to achieve optimal resolution while simultaneously preserving sensitivity. The findings of this study indicate that an increased amount of energy originating from the hand is successfully transmitted to the sensor. The development of this blood sugar monitor is currently underway. The GlucoTrack blood glucose meter is a non-invasive device that allows the measurement of blood glucose levels without the need for traditional invasive methods such as finger pricking. In this study, we employ a novel approach to measure three distinct criteria using a combination of ultrasonic, electromagnetic, and thermal techniques. These criteria are important in various fields, including but not limited to [insert relevant fields]. By employing a multimodal approach, we enhance the accuracy and reliability of our measurements, thereby contributing to the advancement of scientific knowledge in this area. The GlucoTrack company offers a personal ear clip equipped with sensors and calibration circuitry. This innovative device provides users with a convenient and efficient means of monitoring their glucose levels. Using advanced technology, GlucoTrack has developed a product that offers accurate and reliable readings. The Personal Ear Clip is designed to be user-friendly, allowing individuals to easily track their glucose levels in a non-invasive manner. With its sophisticated sensors and calibration circuitry, this device ensures precise measurements, providing users with valuable information for managing their diabetes. Currently, the primary unit under consideration has not yet been made available for purchase or received approval from the Food and Drug Administration (FDA).

Furthermore, its level of accuracy is currently constrained. The investigation of glucose monitoring patches using temporary tattoo technology is currently ongoing. The present study aims to investigate the dispersion delay of glucose sensors by specifically comparing the delay of minimally invasive glucose sensors with that of another type of sensor. Dispersion delay refers to the time it takes for the sensor to accurately measure and report glucose levels in the body. In this study, we observed that the sensor under investigation exhibited a longer dispersion delay than minimally invasive glucose sensors. This finding suggests that the sensor in question may take more time to provide accurate glucose readings. Minimally invasive glucose sensors have been widely recognized for their ability.

Proposed research work

The objective of our work is to develop a non-invasive and accurate method for monitoring glucose levels in the human body. Glucose measurement is of utmost importance in the field of healthcare, particularly for individuals with diabetes. Traditional methods of glucose monitoring involve invasive procedures such as finger pricking for blood sampling.

The inherent variability of tissue dielectric properties in response to changes in glucose levels necessitates the development of microwave sensors that can effectively reflect, transmit, and absorb microwaves. In recent years, there has been a growing interest among researchers in investigating the relationship between glucose concentration in blood and its dielectric properties. This surge in interest has subsequently resulted in a rise in research focused on microwave sensors. **Table 2** details of the research work done with antennas for glucose monitoring and measurement.

Table 2. Literature review of the antenna for glucose measurement.

Reference	Authors	Work Done
[29]	Saha et al.	1. Collection Method: Pig blood samples were acquired from a slaughterhouse and stored in 9-mL test tubes containing K3 EDTA for subsequent analysis. 2. Simulation Parameters: The magnitude of the reflection coefficient was simulated by varying glucose concentrations of 0, 125, and 250 mg/dL. 3. Observed Effect: Changes in glucose levels from 0 to 125 mg/dL or 125 to 250 mg/dL resulted in a notable shift in the resonant frequency of physiological saline-glucose solutions of approximately 5 MHz. 4. Limitations identified: a. Sample Preparation: Use of 25 mL volumetric flasks may incorrectly represent the actual blood glucose concentrations of the pig. b. Reference Sample Accuracy: The reference sample used for the determination of glucose levels may not accurately reflect pig blood glucose levels. c. Simulation Accuracy: The magnitudes of the simulated reflection coefficients may not completely mirror the sensor's real-world behavior. d. Glucose Concentration Range: The chosen glucose concentrations for simulations may not cover the entire spectrum encountered by the sensor in practical scenarios.
[30]	Vrba et al.	1. Assessment Method: Using S21 parameter analysis, the evaluation of the glucose monitoring device involved measuring the transmission of a glucose solution and contrasting it with pure water at a specific frequency and thickness, specifically at 6.0 GHz. 2. Signal Change Analysis: ΔS21 was correlated with variations in glucose concentration (Δg). We observed that the primary factor influencing the transmitted signal was the alteration in the imaginary part of the relative permittivity of the glucose solution (εg). 3. Limitations: a. Sample Representation: The assessment focused solely on glucose solutions rather than actual blood samples, potentially limiting the real-world applicability of this device. b. Specificity: The device did not measure glucose specificity in distinguishing it from other blood substances. This raises concerns as to the possibility of false readings if other blood components, such as different sugars or proteins, affect the transmitted signal similar to glucose. c. Accuracy of Estimates: The expected change in S21 due to a glucose spike was estimated based on theoretical calculations and controlled sample sensing measurements. These estimates may not accurately reflect the device's performance in real-world scenarios.
[31]	Xiao and Li	1. Testing and Reliability: Evaluation of a dispersive testing method over a range of blood glucose concentrations from 0 to 4000 mg/dl. The energy of the received signals at 6.5 GHz is consistent, confirming the reliability of the proposed approach. Validation was further established by obtaining consistent results for experimental signals at 6.5 GHz across a realistic earlobe phantom, covering a range of human blood glucose concentrations from 0 to 400 mg/dl. 2. Limitations: a. Accuracy beyond the tested range: The accuracy and reliability of the method might not extend beyond the tested range of 0–4000 mg/dl, raising concerns about its applicability to concentrations beyond this range. b. Single Frequency Testing: The assessment solely focused on a single frequency (6.5 GHz). Consequently, the accuracy and reliability at other frequencies remain uncertain. c. Phantom vs. Human earlobes: Experimental signals were exclusively tested on a realistic earlobe phantom, omitting real human earlobes from the evaluation. This omission introduces doubts regarding the compatibility and accuracy of the method when applied to actual human subjects.

Table 2. (*Continued*).

Reference	Authors	Work Done
[32]	Mahnashi et al.	1. System Description: The system employs RF microstrip patch antennas for the transmission and reception of microwave signals. Subsequently, these signals undergo processing to ascertain the glucose concentration within the sample. Testing conducted using glucose-water samples indicates the system's capability to accurately detect glucose levels within a range spanning from 0 to 5000 mg/dL. 2. Limitations: a. Sample Representation: The system's verification solely relies on glucose-water testing samples rather than real blood samples. This limitation raises concerns about the system's performance and accuracy in real-world scenarios where actual blood samples are utilized. b. Limited Glucose Range: Testing was confined to a narrow range of glucose concentrations (0-5000 mg/dL). Consequently, doubts arise regarding the system's accuracy and reliability beyond this specified range.
[33]	Sindhuja and Kanniga	Our Work: 1. Sensor Development: We developed a flexible antenna sensor operating at 4.1 GHz on a polyimide substrate. The sensor detects alterations in blood dielectric properties due to the presence of glucose, enabling more precise glucose level predictions. Our method uses subband energy levels from the Degel polyimide antenna coupled with a quadratic regression algorithm, to make accurate glucose level predictions. 2. Simulation and Potential Application: We Studied antenna performance through simulations for potential glucose sensing within the human body by using 3-D electromagnetic modelling. However, real-time testing of the proposed flexible antenna sensor in practical scenarios is yet to be conducted. 3. Advantages of Flexible Antennas: Our method emphasizes the benefits of flexible antennas for medical wearable applications over conventional rigid antennas. Flexible antennas present promising advantages in terms of comfort and usability for medical wearables. 4. Noninvasive glucose testing: We highlighted the noninvasive nature of epidermal glucose testing, eliminating the need for invasive blood drawing.

2.4. Flow diagram

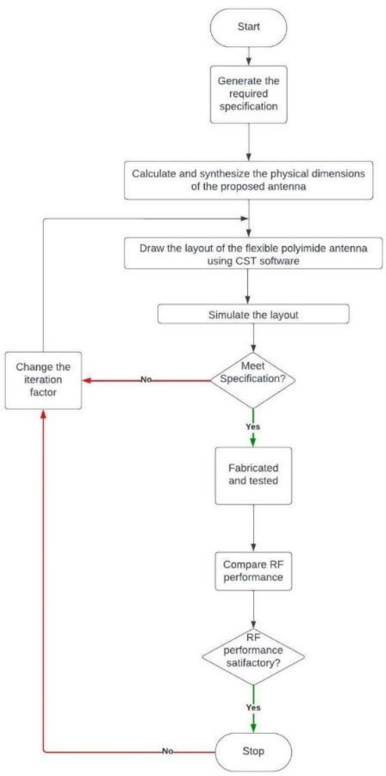

Figure 11. Flow diagram.

To create an efficient flexible patch antenna, follow these steps as given in the **Figure 11**:

1) Generate Antenna Specifications: Define operating frequency, gain, and constraints.
2) Calculate and Synthesize Dimensions: Determine patch dimensions based on frequency.
3) Layout Design Using CST Software: Create the antenna layout in CST Studio Suite.
4) Simulate and Validate: Verify performance through electromagnetic simulations.
5) Fabricate and Test: Measure antenna behavior in controlled conditions.
6) Evaluate RF Performance: Assess gain, efficiency, and adjust as needed.

2.5. 3D electromagnetic modeling of the human thumb

Figures 12 and **13** illustrates our meticulously crafted 3D electromagnetic model of the thumb using CST Microwave Studio. Our model incorporates several layers, each contributing to its hyper-realistic representation. We begin by defining a typical human thumb with the following dimensions:

- Length: 25 millimeters
- Width: 15 millimeters
- Height: 12.3 millimeters

Next, we explore the impact of blood glucose levels on our model. By varying glucose concentrations from zero mg/dL to a staggering 16,000 mg/dL, we simulate the thumb's electromagnetic response. Our investigation extends to sensitivity analysis. Researchers have extensively studied this aspect, and our findings align with their work. Specifically, we focus on the sensitivity of the proposed Degel polyimide antenna.

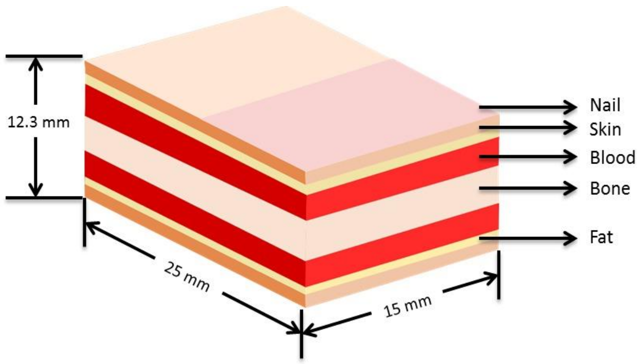

Figure 12. 3D electromagnetic model of thumb tissue in CST Microwave Studio.

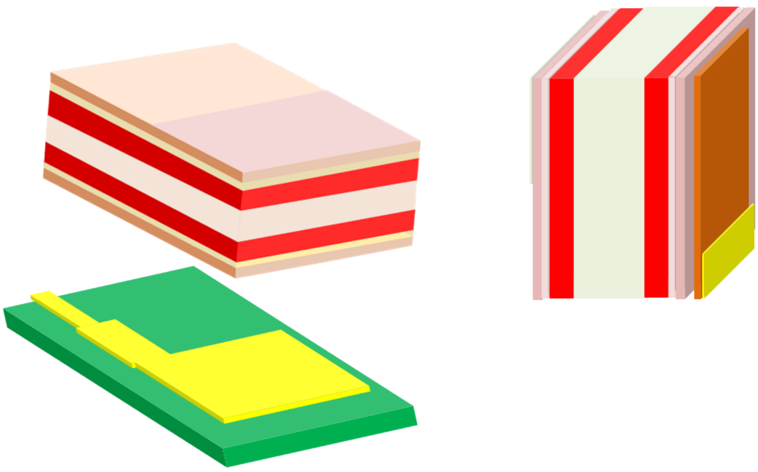

Figure 13. Degel–polyimide antenna with simplified EM thumb model.

From **Figure 14** we observe the variations in the glucose concentrations and the corresponding changes in the frequency are recorded in **Table 3**. The sensitivity (Δf) can be calculated using the following formula:

$$s = \frac{\Delta \mathrm{f}}{\Delta \mathrm{c}}$$

s = 4102-4080/16000−0 KHz/mgdL

= 1.375 KHz/mgdL

This sensitivity implies that the antenna can precisely detect small fluctuations in glucose concentration. Such accuracy holds promise for monitoring individuals with diabetes or other glucose-related disorders.

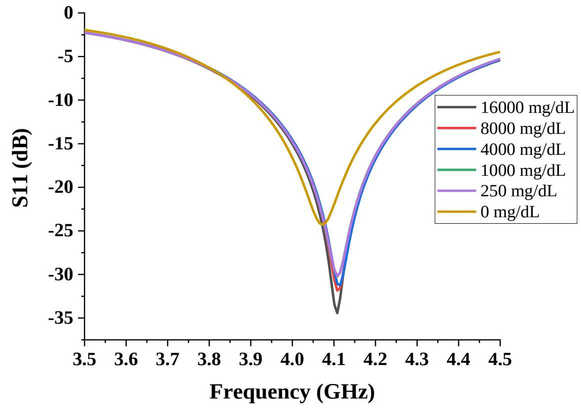

Figure 14. Reflection coefficient plot demonstrating the performance of the developed flexible antenna across different glucose concentrations.

Table 3. Resonance frequency shifts according to varying glucose values.

Glucose Concentration (mg/dL)	Resonance Frequency (GHz)	Glucose Concentration (mg/dL)
0	4.08	0
250	4.125	250
1000	4.175	1000
4000	4.15	4000
8000	4.115	8000
16000	4.102	16000

3. Conclusion

In the context of a projected global diabetic population of 366 million in 2021, diabetes remains a significant problem for numerous nations, including India. The prevalence of diabetes among the Indian population is now on the rise. While this topic exhibits certain positive attributes, it is imperative to acknowledge and handle its negative aspects as well. One prominent issue is the escalating mortality rate associated with diabetes mellitus.

The prevalence of diabetes is a significant public health concern in contemporary society. India exhibits a substantial prevalence of diabetes, as evidenced by a population of over 4 million individuals grappling with this ailment within the nation. According to the World Health Organization (WHO), it was anticipated that in the year 2015–2016, more than 5% of the Indian population would be afflicted with diabetes[34]. Diabetes research in India encompasses two primary domains: clinical research and fundamental research. Clinical research encompasses scholarly articles originating from various healthcare institutions, such as hospitals, clinics, and universities, with a primary emphasis on patient care and therapeutic interventions. The primary focus of basic research investigations is to investigate the etiology of diabetes, explore strategies for mitigating its incidence, and identify optimal treatment modalities and preventive measures currently used.

The study of diabetes in India has resulted in numerous scientific and medical breakthroughs. Individuals with diabetes today can effectively manage their condition through regular monitoring of blood glucose levels, as well as careful control and monitoring of their dietary intake and prescription usage. A wide range of gadgets is now employed for diabetes management. Certain technological items have been explicitly developed to cater to the needs and preferences of the Indian population, while others have been designed by drawing inspiration from Indian esthetics and design principles.

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Conflict of interest

The authors have no conflict of interest.

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