Millimeter and Microwave Sensing Techniques for Diagnosis of Diabetes

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Abstract Diabetes mellitus is a metabolic syndrome described by hyperglycemia derived from insulin secretion, insulin action, or combined form deficiencies. Diabetes is considered one of the emerging epidemics of this century; this necessitates the research on the early diagnosis and essential control of diabetics. Along with the diagnosis and treatment of this disease, it is crucial to give due importance to the studies on the prognosis and prevention measures for diabetes. In the present chapter, the non-invasive millimeter and microwave sensing techniques are summarized that can be helpful for the prognosis and diagnosis of diabetes. These

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techniques are commonly used in measuring the dielectric properties of solutions such as glucose parameters and used in non-contact or subsurface skin sensing. Invasive methods cause discomfort and pain during diagnosis, as it takes blood drops to monitor glucose levels in the body. Millimeter and microwave sensing techniques have the potential for developing a medicinal gadget that non-invasively measures the blood glucose without following the usual procedure of finger pricking, taking a drop of blood, and using the test stripe; this facilitates minimum hassle and the best possible way to deal with the samples to examine and diagnose blood glucose levels. Painless glucose testing methods can aid in the proper management of diabetes for people of all ages, as current approaches like continuous glucose monitors or finger-prick tests cannot guarantee appreciable efficiency or convenience.

Keywords Prognosis · Diabetics · Millimeter · Microwave · Non-invasive

1 Introduction

1.1 Overview

Diabetes is a physiological chronic illness/disease where a person develops the potential to undertake blood glucose processing known as blood sugar in the impaired form [1]. The total number of human beings affected globally due to diabetes has quadrupled in three decades. In this current century, every 1/11th person is affected due to diabetes. Asian countries, including China and India, are becoming new epicenters of diabetes patients in the coming decades throughout the world. From a clinical perspective, whenever a situation under medical diagnosis of a person is referred towards abnormal grades of sugar level in the blood, they are said to be diabetic or are suffering from a form of Diabetic Mellitus (DM) [2]. Diabetes is a mystery illness; physician Aretacus made this prognosis of Cappadocia (81-138 AD), which still holds today [3]. For almost two millenniums or even after a brief time of two millennia, the root cause of diabetes aliment remains obscure. Variable or abnormal sugar levels in some cases indicate binary levels of a pre-existing condition in the sample of the affected person, and this condition is referred to as hyperglycemia or hypoglycemia. The first condition, i.e., is the production of excessive amounts of glucose. The latter says hypoglycemia lowers the production of excessive amounts of glucose. The latter says hypoglycemia lowers the glucose level in the normal range.

1.2 Types of Diabetes

Diabetes is classified into the following three types:

I. Type 1 diabetic
II. Type 2 diabetic
III. Type 3 diabetic, i.e., Gestational diabetes (Fig. 1).

1.2.1 Type 1 Diabetics (Auto-Immune Condition)

Type 1 diabetics are also known as Juvenile diabetes [5]. The juvenile form of diabetes is due to the incapability of a person's body to produce insulin. Insulin is a hormone responsible for allowing glucose to enter cells as energy while also keeping glucose levels in the bloodstream at normal ranges. It is necessary as it helps supply energy to the body to carry out routine activities and promote day-to-day functions. In general, for type 1 diabetic patients, the physical management/metabolism becomes dependent on insulin. Therefore, artificial insulin is to be injected in one form or other daily for the person to stay alive.

1.2.2 Type 2 Diabetics (Permanent Chronic Condition)

In type 1 diabetes, the immune system mistakenly attacks the insulin-producing beta cells in the pancreas. It causes permanent damage and prevents the pancreas from

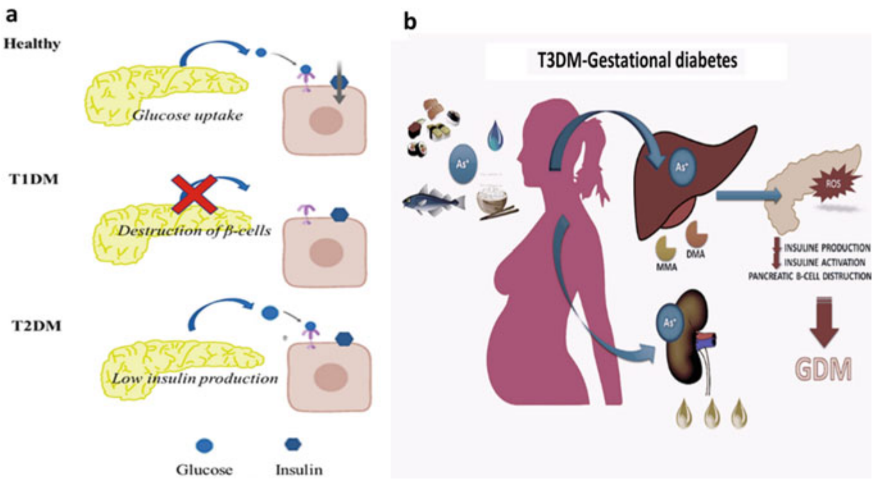

Fig. 1 Schematic representation of the three different types of diabetics: **a** Type I, Type II (Reproduced with permission from [3] CC By © 2019 by Vieira et al., Licensee MDPI, Basel, Switzerland) and **b** Type III: Gestational diabetes (Reproduced with permission from [4] CC By © 2019 by Salmeri et al., Licensee MDPI, Basel, Switzerland)

producing insulin. The body generally produces insulin in such chronic conditions, but it is not effectively used up as it would have [6].

1.2.3 Type 3 Diabetics (Gestational Diabetes)

Hyperglycemia and gestational diabetes are globally becoming significant public health issues during the stage of pregnancy in women. Although not all pregnant women are affected by this condition, the onset increases risks during pregnancy. Sometimes it causes problems for newborns and sometimes does not favor the proper birth process. However, this condition mostly subsidizes after the birth of a child [7]. The consequence of gestational diabetes cannot be ignored once and for all the time (Fig. 2).

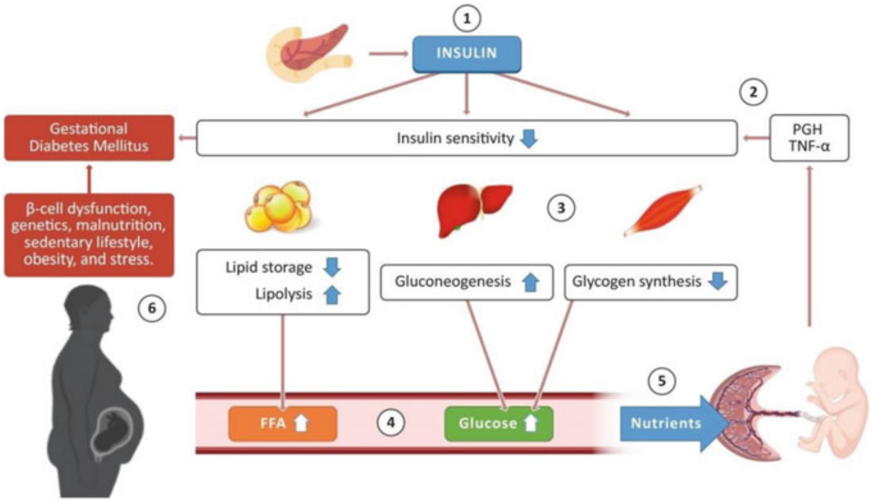

Fig. 2 The process of gestational diabetes. The pancreas distributes insulin, which stimulates specific activities in certain tissues to control blood sugar levels in the blood (1). Through a healthful gestation, the placenta generates the placental growth hormone (PGH) and proinflammatory cytokines such as tumor necrosis factor-alpha (TNF-α), stimulating a reduction in insulin sensitivity in adipose tissue, liver, and skeletal muscle (2). As a result, fat tissue limits lipid storage and promotes lipolysis; the liver promotes indigenous glucose (gluconeogenesis); skeletal muscle glycogen fusion is reduced. (3). Free fatty acids (FFA) and glucose levels in the blood rise because of such activities. (4), They are essential as nourishment for the placenta and fetus' growth (5). Nonetheless, certain pregnant women have susceptible factors that cause gestational diabetes mellitus (Reproduced with permission from [8] CC By © 2019 by Lizárraga et al., Licensee MDPI, Basel, Switzerland

Less common types:

I. Monogenic diabetes
II. Cystic fibrosis diabetes.

2 Diagnosis of Diabetes

“Endocrinology 2.0,” as suggested by existing textbooks monographs and scientific journals, suggests that hormones play an essential role in diagnoses which are thus ignored by current medical practitioners [10].

Obesity is still considered one of the regular signs for identifying diabetes mellitus (Fig. 3). Currently, 354 million diagnosed and undiagnosed diabetic patients are present in the world [11].

The current diagnostic methods for diabetes include extraction of medical analysis samples through urine, blood which are generally invasive methods where the affected body of a patient is invaded for sampling.

Invasive and Non-invasive

In the last ten years, point-of-care devices (POCD) have played a significant role in detecting diabetes as they are made to check the glucose levels in the blood, such as glucometers. The POCD is categorized into invasive or minimally invasive

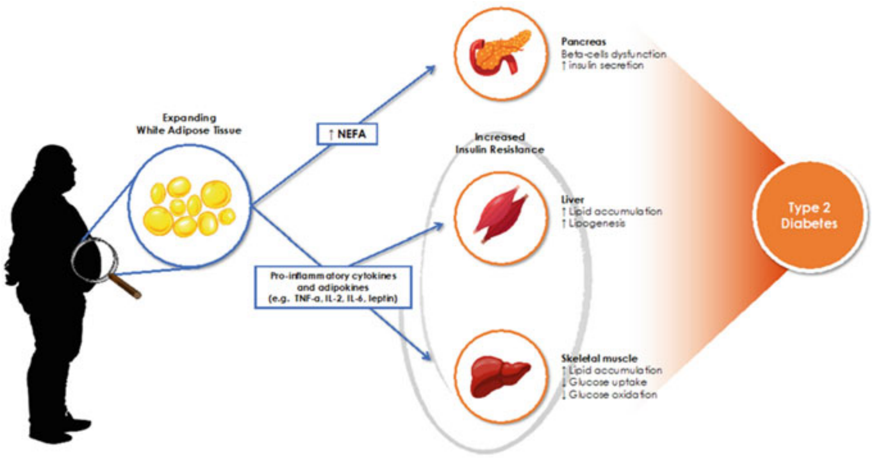

Fig. 3 Schematic illustration of connection amongst obesity on type 2 diabetes (NEFA-Non-esterified fatty acids) (Reproduced with permission from [12] CC By © 2019 by Hwalla et al., Licensee MDPI, Basel, Switzerland)

nature; after collecting blood from the tip of the finger, an approximate calculation of glucose is made. The chemical reactions involved are enzymatic glucose-oxidase, glucose-fragments binding, glucose spectral features, color reflectivity, etc. An electrical signal is then applied to the glucose concentration to induce it. Blood is collected from the fingertip is a painful process prone to infection and has high costs. Hence, a non-painful and invasive free biosensor technique for monitoring glucose levels has been developed. Research has been undertaken in the last ten years and is still ongoing to create a suitable substitute as a non-invasive glucose testing device (NGD). This strategy is adopted by companies that produce clinical equipment and is used for non-intrusive glucose assessment. Various devices are mentioned in Table 1 and summarized, along with their manufacturers, advantages, and disadvantages. Some techniques such as Raman spectroscopy, optical coherence tomography (OCT), fluorescence technique, light scattering, photoplethysmography (PPG), photoacoustic and near-infrared (NIR) are all-optical techniques that depend on rays of light at various wavelengths for the identification of glucose concentration by using optical parameters. This concept is used for developing NGD devices [13].

Red/near IR or mid-IR absorbance spectrometry techniques employ the splitting of luminosity at living tissue aiming towards observation or notice of any visual marks of sugar content occurring in blood. These procedures involve several drawbacks such as high pricing vulnerable to fluctuations in physiological parameters like body temperature, blood pressure, the pressure of the atmosphere, temperature, or humidity. Another procedure for detecting glucose levels indirectly is by electrochemical techniques, which monitor external fluids of the body like saliva, breath condensate, sweat, or tears. Later, a comparison between measured glucose concentration to the amount of glucose in the blood is carried out. Although the non-invasive techniques have better sensitivity, they are criticized for being vulnerable to metabolic changes. Apart from that, they are weakly associated with glucose levels in the blood because of the disparity between changes in sugar concentration in interstitial fluid (ISF), sweat, or blood. The suggested ideas seem to be in their infancy, making it hard to assess their usability [13, 14].

Figure 4 illustrates various classifications and arrangements to monitor blood sugar levels: invasive, minimally, and non-invasive. Bedside medical equipment or personal assessment care meters are examples of fully intrusive systems. Moreover, monitors are designed for intensive care units and employ sensitive sensors within 1%. Continuous monitoring is achievable with these devices, which increases the quantity of available clinical data. Typical approaches like drawing blood from the skin are still used in homes (precision of six to seven percent). Sugar content is found via electrochemical, colorimetrical, or optical replicable stripes for finger-stick blood samples. Attempts have been made to achieve a lower risk of invasiveness; by reducing the amount of blood taken to only a few microliters and measuring body regions that are less sensitive to pain, e.g., forearm, upper arm, or thigh. Some disadvantages like lack of accountability when sleeping or while performing manual tasks, unnoticed periods of hyper-or hypoglycemia, infection risks, nerve damage, and the uneasiness of puncturing the finger multiple times a day, etc., often lead to non-compliance of the technique [15–17].

Table 1 Gadgets for non-invasive blood glucose monitoring available in the market (Reproduced with permission from [13] CC By © 2019 by Omer et al., Licensee MDPI, Basel, Switzerland)

Device/company	Technique	Placement	Needs	Attributes
NovioSense (Noviosense BV)	Electrochemical enzymatic-based tear analysis	Lower eye lid (inferior conjunctival fornix)	Continuous monitoring provided a sample	Compact, painless, flexible, wireless power, smartphone connected for data analysis
Smart Contact Lens (Novartis & Google)	Electrochemical enzymatic-based tear analysis	Eye	Continuous monitoring provided a sample	Painless, power efficient, portable, low relief, hazardous when overheated, withdrawn from market!
iQuicklt Saliva Analyzer (Quick LLC)	Saliva analysis	Saliva of the mouth	Intermittent monitoring provided a sample	Portable, convenient to use, accurate, time efficient (real-time readings), under development and clinical trials
TensorTip Combo Glucometer (Cnoga Medical)	Photometric and photography-based techniques	Fingertip	Intermittent monitoring without a sample	Convenient to use, accurate when calibrated on individual-basis, smartphone compatible, battery operated (rechargeable), cost-effective, certified!
Glucosense (Glucosense Diagnostic Ltd.)	Low-powered laser sensors that use photonic technology (infrared light)	Fingertip	Intermittent monitoring without a sample	Convenient to use, portable, affordable, power-efficient, time-efficient (30 s), under development!
Groves's Device (Groves Instrument Inc)	NIR spectroscopy	Fingertip or earlobe	Intermittent monitoring without a sample	Fast processed readings, time-efficient (20 s), compact, portable, uses capillary-level blood, less accurate due to lacking subjective calibration

(continued)

Table 1 (continued)

Device/company	Technique	Placement	Needs	Attributes
GlucoTrack (Integrity Applications)	Thermal, ultrasonic, and microwave EM technology	Earlobe	Intermittent monitoring without a sample	Affordable, convenient use, high accuracy due to earlobe placement, unit-connected results processing/display, complex processing, FDA approved!
GlucoWise (MediWise)	RF/Microwave	Amid fingers (thumb and forefinger)	Intermittent monitoring without a sample	Convenient to use, affordable, accurate, Bluetooth-based data transmission, compact, integrable with insulin pumps, uses capillary-level blood, time-efficient, fast readings (10 s), hurtful due localized energy usage, under development!

The minimally invasive method also causes irritability to the patient as it uses the interstitial fluid sample within intravenous sensors. Even with this approach, the patient's treatment is delayed because of their discomfort. Due to this, research groups have been working to evolve glucose monitoring devices that are non-invasive. Yet, neither patents nor papers show a high level of accuracy for the non-invasive technique compared to the invasive one [18, 19].

Non-invasive Method

An alternative method of painless, intermittent glucose monitoring is blood with other fluids in the body that might contain glucose, like tears, sweat, urine, or saliva. On the other hand, constant tracking can be achieved by directly measuring body tissues such as skin, eye, oral mucosa, tongue, or tympanic membrane.

It is possible through non-invasive glucose monitors, which differentiate glucose information from other overlapping components (proteins, urea, uric acid, hemoglobin, water, etc.). Similar sensors can detect blood sugar levels either directly, depending on the chemical composition of the glucose molecule, or by monitoring the impact of blood sugar on other procedures, for example, temperature or pH shifts.

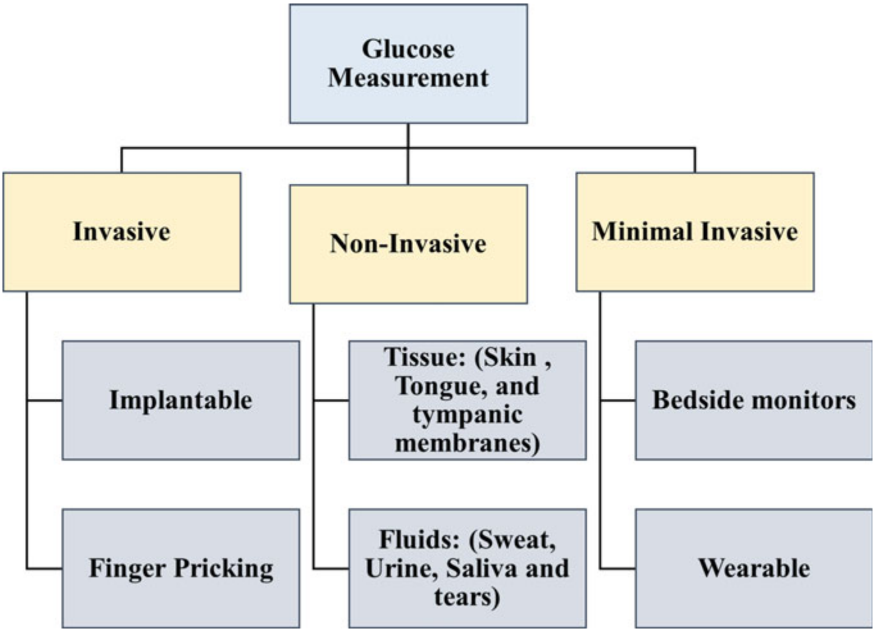

Fig. 4 An overview of non-invasive blood glucose management systems

Reverse iontophoresis, polarimetry, metabolic heat conformation, ultrasound, thermal emission, electromagnetic, photoacoustic, Raman, light absorption, and bioimpedance spectrometry have been used throughout various non-invasive studies. In addition to the methodology and sample region, the measurement surroundings should also be considered. Sweltering, skin shade, surface bumpiness, skin thickness, exhaling artifacts, the flow of blood, bodily motions, ambient temperature, pressure, and slow response all impact the results in transdermal monitoring [14](Fig. 5).

The most difficult aspects of developing fully non-invasive blood sugar examining technology are precision, serviceability, and appropriateness for easy handling at home by many persons. The best way to overcome these challenges is to develop a device that will create a significant breakthrough in this field (Fig. 6). A gadget like this can replace the existing benchmark of intrusive glucose biosensors and enhance the lives of millions of diabetic patients around the world. However, many systems still have several significant drawbacks, including low glucose sensitivity and specificity and the need for a lengthy and frequent calibration. This shows how difficult it is to balance generalizability and application. It is vital to make the device usable and acceptance level assessment better, which may reveal main user problems and provide a significant action in the commercialization of these gadgets.

The inability of existing non-invasive gadgets to replace a standard glucose measuring meter is one of its primary drawbacks. As a result, these devices must be constantly improved to improve the algorithm, software, and device features to increase their performance further. Furthermore, more clinical research is needed

Fig. 5 Skills in advancement for minimally and non-invasive glucose detection (Reproduced with permission from [20] CC By © 2019 by Villena Gonzales et al., Licensee MDPI, Basel, Switzerland)

Fig. 6 Confronts of non-invasive blood sugar examination. An effective non-invasive glucose monitoring device should surmount the sequence of precision usableness and should face the challenges

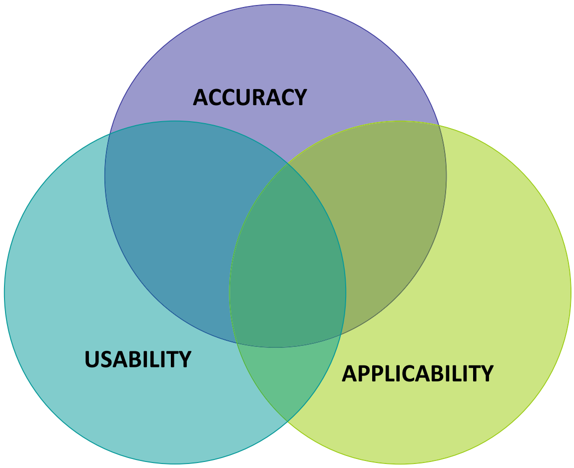

Fig. 7 Schematic illustration of fasting plasma glucose test

to assess whether non-invasive devices will improve glycemic management in individuals. It is similarly worth noting that the existing analysis ignores the issue of inexpensiveness. Consumers may choose non-invasive blood sugar detecting tools because they do not need lancets or strips, though several methodologies that have been reviewed are expensive [21].

2.1 Testing Methodologies

The testing methodologies/methods of diabetes include [22].

I. Fasting plasma glucose (FPG).
II. A1 C test.
III. Random plasma glucose.

2.1.1 Fasting Plasma Glucose (FPG) Test

The FPG methodologies are an instantaneous measurement parameter that requires pre-condition of receptor's body to fast for at least 8 h, except sips of water intake. The fasting condition is generally done at night, and tests are conducted in the morning for reliable results [23] (Fig. 7).

2.1.2 The A1C Test (HbA1C, Glycated Hemoglobin Test)

As opposed to the FPG test, the A1C/HbA1C test is used to diagnose not affected/inconsistent overeating and drinking before the test. The chart of the A1C test is shown in Fig. 8. Averaging down sugar levels over 3 months is considered to provide accurate sugar levels in the blood.

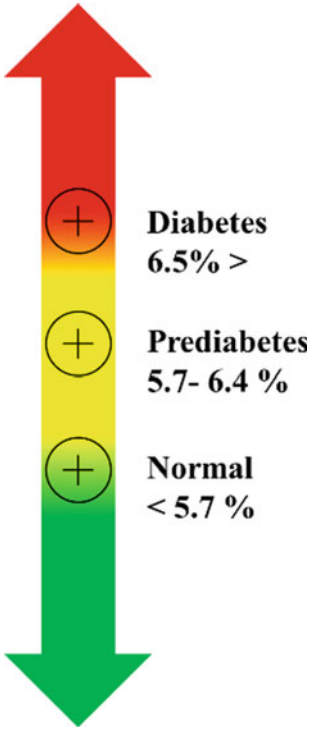

Fig. 8 The A1C test results

Other symptoms such as age, anemia, or other stipulated problems are also considered during the tests undertaken. This is done because the A1C test is inconsistent when the person does not have anemia or any other blood-related disorder.

2.1.3 Random Plasma Glucose (RPG) Test

Sometimes health care professionals use the RPG test for diagnosing the symptoms in a patient. This blood test does not follow any pre-conditions that need to be followed. This can be done at a given time of day. The glucose challenge test is used through the oral testing methodology for pregnant women. Oral glucose tolerance test requires fasting for about 8 h and then taking glucose. This is done by drawing blood every hour 2–3 times (Fig. 9).

Pre-diabetes

A combined study in 1997 and 2003 by the authority board on the diagnosis and categorization of diabetes mellitus could recognize a group of individuals whole glucose were neither in the range of classified diabetes patient. Still, it was high enough to be not classified with the normal levels. Such a condition on the borderline is referred to as pre-diabetes by medical professionals. A1C (5.7–6.4%) (39–47 mmol/mol).

Fig. 9 RPG test

It can be considered as an increased risk for diabetes. Generally, it is measured in cases of diabetes which is supposed to have obesity dyslipidemia with extreme triglycerides and/or to have a low-level HDL cholesterol and hypertension.

3 Millimeter and Microwave Techniques for Sensing

3.1 Background: Mechanism of Millimeter and Microwave Techniques

The well-known microwave frequency band stretches around 300 MHz to 30 GHz, while the millimeter wave spectrum spans in the range of 30–300 GHz; the subsequent wavelength ranges are 1000–10 mm and 10–1 mm, correspondingly. The frequency and wavelengths correlated with microwave and millimeter waves are shown in Fig. 10. These frequencies allow interrogating signals to permeate dielectric objects and react with their interior composition. The millimeter microwave sensors provide useful spectroscopic approaches that do not necessitate exact alignment [24]. This technique focuses on microwave spectroscopy, also known as dielectric spectroscopy. Because there is less dispersion by the tissue, millimeter and microwave radiation can penetrate deeper into the tissue [25]. In this approach, mm-wavelengths are commonly employed in parts that use soft tissue's reflection and absorption features. The link between mm-wavelength radioactivity and blood sugar decreases permittivity as the sugar level rises. On the other hand, the conductivity increases in response to a rise in blood sugar levels [26]. Radar, reflection, resonant perturbation, and transmission are the four techniques used in mm-wavelength sensing [27].

The radar technique involves transmitting an electromagnetic signal to an object close to the transmitter [28]. The statistics, which comprises the dielectric characteristics of blood glucose, will subsequently be sent to the receiver by the transmitter. This is distinct at various glucose concentrations [28]. The primary data is evaluated

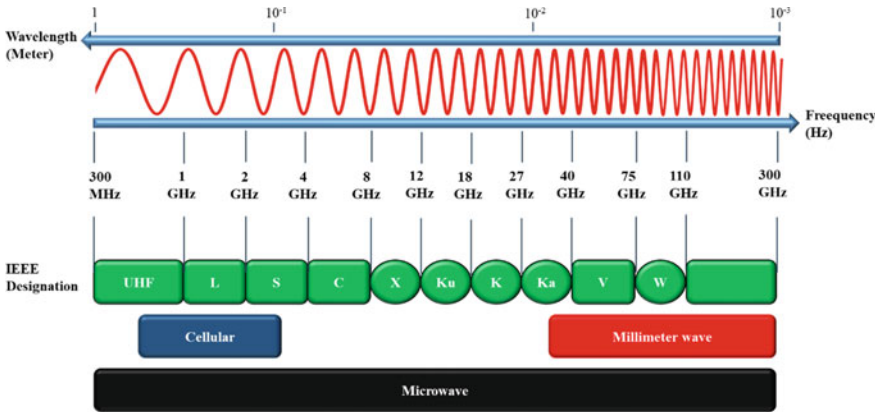

Fig. 10 Millimeter wave in the spectrum band

using traditional signal processing methods, which aid in identifying blood glucose levels [29].

The fundamental goal of the mm-wavelength sensing reflection method is to quantify the reflection boundary for detecting the changes in permittivity due to blood glucose variations. Using a coaxial probe, the reflection factor estimates the permittivity, which leads to blood glucose monitoring by reflection in the mm-wave sensor [30]. A vector network analyzer, such as the Anritsu 37397C, measures the reflection coefficient across the open coaxial probe. Similarly, an antenna can be used in the open coaxial probe sensor attached to the vector network analyzer [31]. The resonant frequency is relevant in determining shifting blood sugar substances related to the reflection coefficient. The link between resonant frequency and variable sugar levels in the blood is assumed to occur with the drop in the intensities of resonant frequency, which occurs by the rise in glucose concentrations.

The resonant perturbation approach offers some of the greatest sensor execution for mm-wavelength light to date [27]. This method aims to determine resonant frequency fluctuations and link such changes to dielectric characteristics. The microfluidic subsystem design and the substrate integrated waveguide (SIW) re-entrant cavity resonator model are the two aspects of this particular method. A microfluidic-integrated SIW re-entrant cavity with a quality element allows evaluating dielectric characteristics of fluids such as the blood samples [32]. When these two systems function together, they provide a sensitive and accurate sensor. Transmission approaches are comparable to reflection techniques in which the reflection parameters are also evaluated. mm-wavelengths can be used in transmission methods to assess fluctuations in glucose levels based on dense permittivity variations throughout a single channel. A sensor can operate in the K band (27–40 GHz) to carry out the benefits of transmitted data. The transmission method requires two measurement ports, whereas the reflection method requires one. Transmission methods are simply reflection systems, but they operate two times because of dual ports. According to recent research, the transmission coefficient and blood sugar used for examining purposes have a good association [24] (Fig. 11).

Microwave sensing deals with frequency in the range of GHz, having corresponding wavelength frequencies between 10 cm and 1 mm. Signal with wavelength order in millimeter range is often referred to as millimeter waves. The electrical impulses being localized in human bodies can be detected by microwave components acting as distributed elements like phase voltage, current, etc., which changes significantly over physiological extendedness of device dimensions/body on the order of wavelength. Here, quasi-optical techniques can also be deployed for application in millimeter-wave systems [33, 34].

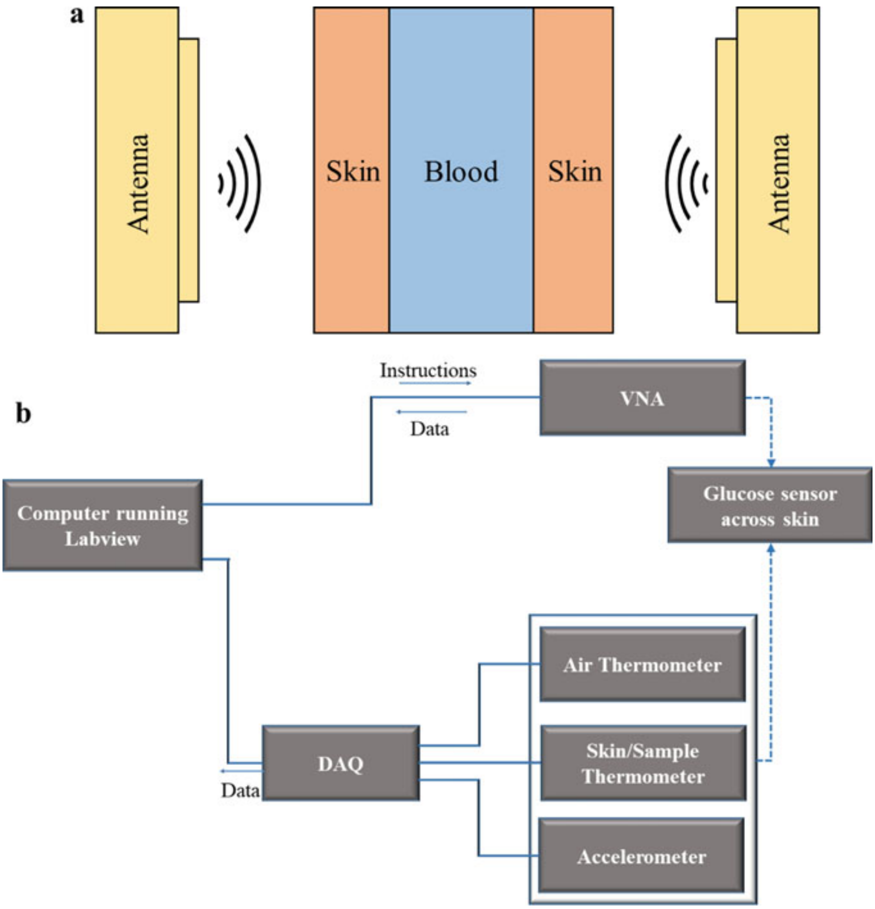

Fig. 11 Millimeter microwave sensor layout for blood sugar recognition. **a** The mm-wave glucose sensor concept is set up with two patch antennas. The skin/blood patient area or a reservoir is located among the two antennas. **b** A diagram of the sensor scheme with data and instruction flow used by Labview

Millimeter and microwave sensing techniques can directly measure the quantities correlated to dielectric properties and, hence, inspect biological material. This technique uses methods such as protein thermal unfolding and refolding lipid bilayer membranes, large aqueous-based molecules, single-cell characteristics, etc. are used in this technique [35]. Here, they introduce a combined millimeter-wave radar system for detecting various glucose levels in laboratory-prepared fake blood models (Fig. 12). The study's goal is to see if mm-wave radars can be used for the non-invasive monitoring of glucose levels in diabetic patients. The proposed concept utilizes signal processing techniques to detect various glucose dilutions and compare them with reflected mm-wave readings. According to the measurement statistics and processed findings, the examined mm-wave radar discriminates glucose dilutions in blood samples across test tubes with extreme sensitivity. This expanded analysis verifies preliminary discoveries and demonstrates a high-resolution recognition capacity. This research also displayed how signal-processing algorithms may process raw records to identify glucose levels accurately. The findings are significant and should open up the way for further research into the possibility of recognizing blood within the physical body [29].

There is another method developed by researchers using the microwave sensing technique for predicting the glucose concentration from the solution of blood plasma. They were designed with three sensors using microwave technology. Figure 13 is the setup of glucose detection using sensors from the blood of a human being. The plasma solution is prepared using various concentrations of glucose, which is added to the blood sample with the addition of ascorbic and lactic acid. The results show an excellent performance of the sensors with good outcomes, and the sensitivity is varied by the amount of glucose [36].

There is a strong relationship between blood glucose concentrations and MMW transmission across the rat ear. It also shows the signal fluctuations above the noise floor when transmitter power is within safe exposure quantities. However, rigid

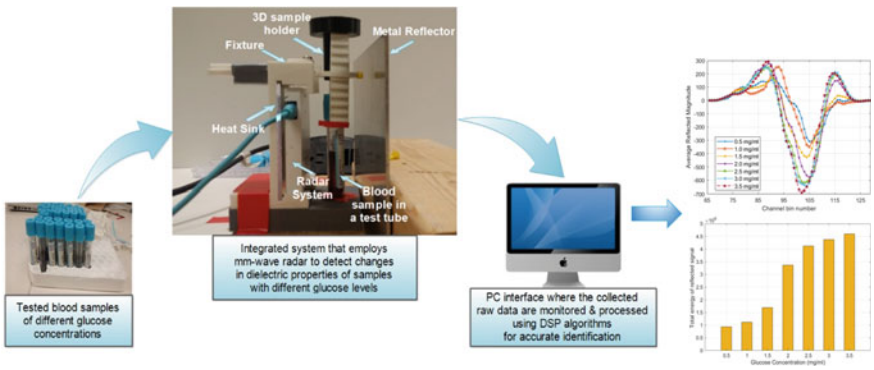

Fig. 12 Test setup: fake blood samples, radar antenna directed to sample tube on a 3-D printed fixture, and PC for supervising/processing (Reproduced with permission from [13] CC By © 2019 by Omer et al., Licensee MDPI, Basel, Switzerland)

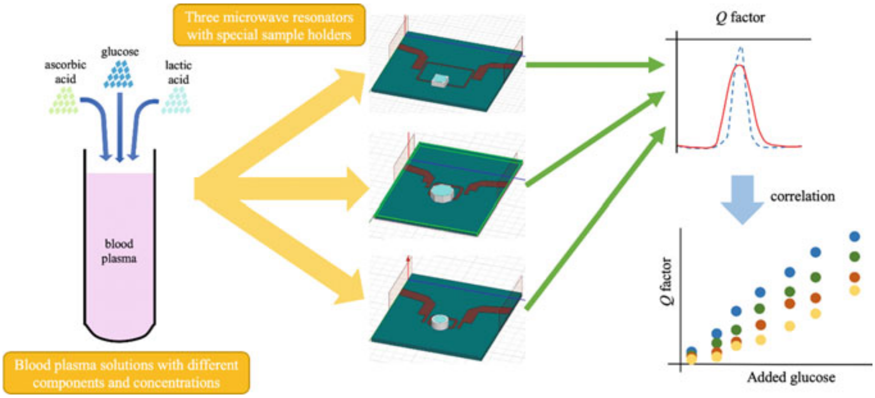

Fig. 13 Measuring glucose from real human blood plasma solutions (Reproduced with permission from [36] CC By © 2019 by the Juan et al., Licensee MDPI, Basel, Switzerland)

waveguide hardware can only be used on immobilized animals. A tiny lightweight fitting containing an MMW CMOS transceiver chipset and an input/output antenna has been designed and built up for active human and animal studies. In addition, experiments were conducted to determine whether the transmission of MMWs via solutions of saline and saline plus sugar could be replicated both in vivo in rat ears and in vitro in the blood (Fig. 14). Measurements in in-vitro and in-vivo, CMOS transceiver design, and packaging of non-invasive glucose monitoring tools are presented in this chapter. Furthermore, millimeter-wave absorption by the solutions having glucose content was evaluated in customized liquid transmission cells, and the results were demonstrated concerning the rat [37].

Fig. 14 Schematic diagram of variations in MMW transmission via the rat ear were evaluated when 1gm/kg glucose, 5 ml saline (control), and 2U/kg insulin is injected

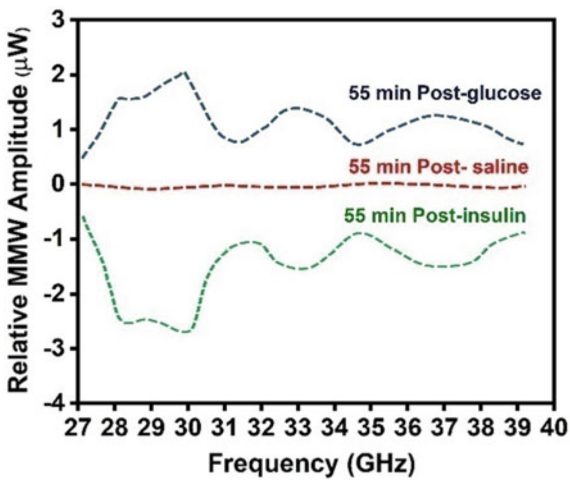

Table 2 The advantages and disadvantages of the millimeter/microwave technique

Method	Advantages	Disadvantages
Millimeter and microwave	• Robust and intense signal saturation • Sharp sensitivity for blood sugar concentration changes • No possibilities of ionization	• Low selectivity • Vulnerable to additional substances in the blood • Susceptible to changes of biological factors, inhaling, perspiring level, and cardiac movement

4 Advantages and Disadvantages

The advantages and disadvantages of the millimeter/Microwave non-invasive technique are given in Table 2.

5 Future Scope

Microwave and millimeter-wave NDT&E have been used in various applications Microwave and millimeter-wave imaging for flaw discovery and assessment in diverse composite constructions using near field focus. Synthetic aperture techniques are a few examples. Biological applications, microwave microscopy, composites, and new uses are constantly being developed. There are several advantages to using microwave and mm-wave NDT&E technologies in near-field applications. These approaches are non-contact, one-sided, and require coupling to transfer the signal into the material under test (unlike ultrasonic approaches). They are also monostatic, low-power, and small. Easily adaptable to existing industrial scanners, real-time in-field operator-friendly does not need operator expertise in the field of microwave engineering allows images with high resolutions to be obtained because the spatial resolution in the near-field is a function of probe dimensions (which in these frequency arrays are quite small) rather than operating wavelength robust, tough and repeatable, as well as sensibly priced [38]. Generally, the non-invasive methods are classified into three: optical, microwave, and electrochemical.

The millimeter microwave method lies in the microwave category, so the other methods do not ensure efficiency or ease of operation. But the main advantage of the millimeter microwave method is the strong selectivity according to the variation of glucose levels. This method has excessive non-invasive behavior, which delivers a continuous examination of blood sugar without inducing difficulties in patients. The proposed benefits of millimeter and microwave properties can be used to perform microanalysis up to the basic functional unit of the body. Synthesis of observational cells and the associated immense ways of diagnostics is to be leveraged for different inventions in the bio-medical field using this technology. Unfortunately, in line with the research studies, the assessed rates may not be closely linked with real sugar levels, and thus the linear range is restricted, necessitating more algorithm modification. Personal characteristics such as old skin tones, skin form, and so on in the sample part will produce huge inaccuracies in the measurement results, resulting in uniformity and steadiness. In terms of analysis, there are certain issues, such as sophisticated detection ways, harsher detecting components, a time-consuming monitoring procedure, detection accuracy support requirements, and significant background signal interference. These constraints can restrict its potential as a household commercial glucose monitor. Suppose more physical parameters such as pH, temperature, humidity, frequency, and other biomarkers involved in blood glucose can be blended to fix the results obtained, improve the performance of painless skin glucose testing and significance to their blood sugar, and achieve continuous monitoring of patients with high blood sugar and low blood sugar. In that case, this could be a promising direction for future research.

6 Conclusion

This chapter evaluated the advancement of research works involved in non-invasive glucose monitoring using millimeter microwave sensing. Non-invasive methods are quite good and less time-consuming than conventional invasive methods. It also offers uninterrupted real-time monitoring of blood sugar levels. This chapter summarizes the different optical and microwave, millimeter-wave biosensor modalities. The millimeter and microwave technologies-based point-of-care devices for glucose level monitoring have been presented. The chapter also discussed the electromagnetic spectrum in which most of the research occurs. We also compared the different glucose monitoring devices existing in the market. Combining all these sections, we have tried to show how all the current aspects, connected to glucose detection, model the technical evolution and development of millimeter and microwave technology that can monitor glucose concentrations non-invasively.

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