1. Huda D. Bader[1,2], 2. Mohammed S. Jarjees[1], 3. Bassam T. Ahmed[1]

Technical Engineering College of Mosul, Northern Technical University, Mosul, Iraq (1)
Medical College, University of Mosul, Mosul, IRAQ (2)
ORCID: **2** 0000-0002-0340-9085;

doi:10.15199/48.2023.11.20

Invasive and Non-Invasive Glucose Monitoring Systems: A Review and Comparative Study

Abstract. *As the incidence of diabetes has expanded worldwide in recent years, an increasing number of patients are experiencing pain and infections because to the invasive nature of the majority of commercial glucose measurement systems. The availability of reliable, low-cost, painless, noninvasive technology will promote patient compliance to routine blood glucose monitoring. The life of the diabetic patient will thereafter significantly improve. Several technologies have been proposed and developed by scientists and researchers in an attempt to enhance their effectiveness. This study reviewed both invasive and non-invasive glucose monitoring techniques, with an emphasis on optical methods. Non-invasive glucose monitoring devices that are painless, sensitive, and transportable are being suggested and developed to better understand glucose levels.*

Streszczenie. *Ponieważ częstość występowania cukrzycy wzrosła na całym świecie w ostatnich latach, coraz większa liczba pacjentów doświadcza bólu i infekcji ze względu na inwazyjny charakter większości komercyjnych systemów pomiaru glukozy. Dostępność niezawodnej, niedrogiej, bezbolesnej i nieinwazyjnej technologii ułatwi pacjentom przestrzeganie rutynowego monitorowania stężenia glukozy we krwi. Życie pacjenta z cukrzycą ulegnie następnie znacznej poprawie. Kilka technologii zostało zaproponowanych i opracowanych przez naukowców i badaczy w celu zwiększenia ich skuteczności. W badaniu tym dokonano przeglądu zarówno inwazyjnych, jak i nieinwazyjnych technik monitorowania glikemii, z naciskiem na metody optyczne. Sugerowane i opracowywane są nieinwazyjne urządzenia do monitorowania glukozy, które są bezbolesne, czułe i przenośne, aby lepiej zrozumieć poziomy glukozy.(* ***Inwazyjne i nieinwazyjne systemy monitorowania glukozy: przegląd i badanie porównawcze****)*

Keywords: ***Keywords:*** Invasive, Non-invasive, Glucose, Optical.
Słowa kluczowe: pomiar glukozy, nieinwazyjny pomiar

Introduction

Most meals include complex carbohydrates, which give energy to cells. Sugars and glucose are produced during the digestion of carbohydrates in food. Glucose molecules are carried by the circulatory system from the gut to the liver and other organs [1]. As glucose levels in the blood rise, insulin is secreted by pancreatic beta cells. Post-meal glucose elimination is aided by insulin [2].Diabetes mellitus is a long-term condition that interferes with metabolism. It is distinguished by unusually high blood glucose levels caused by either the pancreas failing to generate enough insulin due to autoimmune beta cell destruction (type one) or the body's cells reacting incorrectly to insulin due to a gradual loss in beta cell insulin production (type two) [3][4].Diabetes is an opportune disease with a vast amount of information available and enormous problems[5].

To control blood sugar levels, the pancreas secretes the hormone insulin. Beta-cell failure is eventually caused by insulin resistance, poor management of hepatic glucose production, and diminishing beta-cell function in type 2 diabetes. Gestational diabetes mellitus is a condition that may manifest itself in a woman's body during the second or third trimester of pregnancy [6][7].In order to prevent potentially fatal consequences like kidney failure, peripheral neuropathy, and cardiovascular illnesses, it is imperative to keep blood glucose levels within the normal range [8]. Having a glucose level below 60 mg/dL is referred to as hypoglycemia [9]. Contrarily, Hyperglycemia is described as having a glucose level more than 120 or 180 mg/dL whether fasting or eating [9][10]. (see Figure 1).

Diabetes is becoming more common everywhere. The World Diabetes Federation's most current projections show that the prevalence of diabetes among individuals aged 20 to 79 would be 10.5% (536.6 million) in 2021 and 12.2% (783.2 million) in 2045. The prevalence of diabetes was highest in those aged 75 to 79, and it was similar for men and women. In 2021, urban areas were expected to have a higher prevalence (12.1%) than rural areas (8.3%). The global cost of treating diabetes-related ailments was projected to reach $966 billion in 2021 and to increase to $1,054 billion in 2045[11]. These numbers underscore the relevance of diabetes and drive scientists to discover innovative therapeutics to mitigate the disease's detrimental impacts.

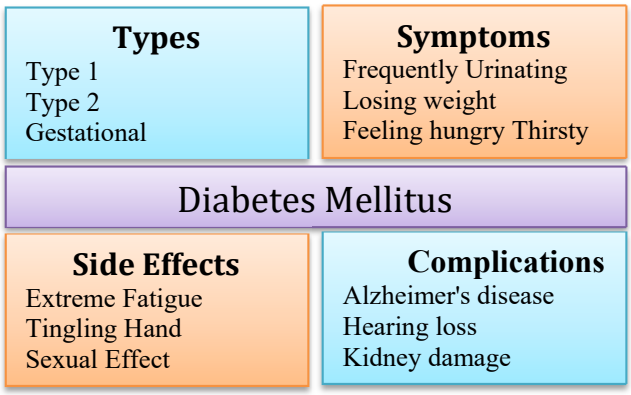

Fig1: Overview of Diabetes

The only way to improve patient with diabetes quality of life and keep them from developing serious consequences is through routine monitoring and control of blood glucose levels [12]. Various sensor kinds have been developed and studied. In 2010 a review study by Toghill and Compton offers a valuable perspective on the enzymatic and non-enzymatic electrochemical glucose detecting methods investigated during the previous decade [13]. Recently, a number of glucose monitoring methods have been created. Based on their mechanism, these technologies are divided into invasive and non-invasive categories [10][11][14]. Figure 2 depicts the majority of blood glucose measuring approaches.

Invasive Blood Glucose Monitoring Techniques

Non-invasive, minimally invasive, and invasive methods are used to detect blood glucose levels. According to the most up-to-date definition of an invasive technology, which is based on a review of medical journal articles, a glucose

monitor is considered an invasive glucose monitor (IGM) if it requires a lancing instrument to be used on the skin to collect blood samples [15]. Traditional methods, which are invasive, include laboratory methods and self-monitoring blood glucose (SMBG) devices, also known as glucometers [16]. Enzymatic-amperometric and hexokinase measurements are the two methods used in clinical labs to determine blood sugar levels [17]. Once patients have fasted overnight, their glucose levels are checked using an automated biochemical analyzer. This approach is not appropriate for continuous diabetes monitoring because of the lengthy process, detection time, and venous blood extraction required. Nonetheless, it might be utilised for identifying diabetic conditions.

Non-continuous glucose monitors (NCGMs) and continuous glucose monitors (CGMs) are the two categories of devices designed for use in self-testing and assessment at home .The frequency of using non-invasive continuous glucose monitoring (NCGM) devices, also known as self-monitoring blood glucose (SMBG), to check blood sugar levels varies from person to person based on their clinical condition, type of diabetes, food, and medication dosage. [18]. In contrast, continuous glucose monitoring (CGM) devices may perform automated checks of blood glucose levels every few minutes, allowing for the identification of fast changes and patterns that would otherwise go unnoticed by SMBG testing. Nonetheless, both methods are suitable for use in self-assessment and point-of-care situations due to their accuracy and reliability [8]. Due to the simplicity of the measurement method and its reliance on capillary blood for precise glucose measurements make SMBG devices the gold standard in self-monitoring [18]. SMBG is the process of checking the blood glucose level at a particular moment in time [19]. SMBG should be taken four times daily, up to ten times daily during illness or poor control, according to medical standards [20].

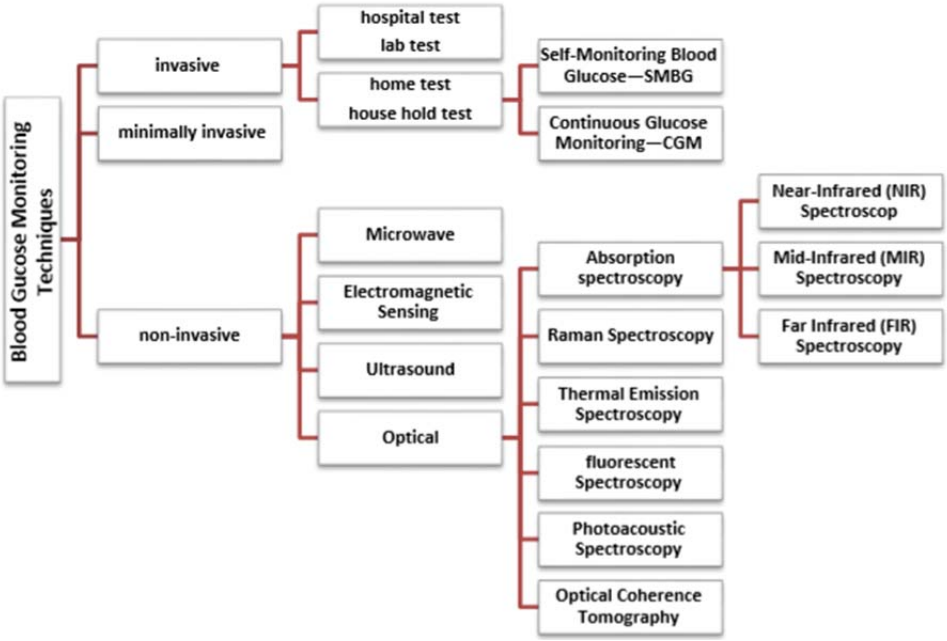

Fig 2. Measurement of Blood Glucose Classification Chart

Self-management tools allow people to measure their blood sugar levels over time and immediately before and after meals [21][22]. Finger-prick testing, an enzyme-based method of collecting blood from a fingertip and measuring it in vitro using test strips and a blood glucose metre (glucometer), is presently the most common method of self-monitoring [23][24][25]. Figure 3 depicts this. It is not a continuous way of monitoring blood sugar levels and must be repeated many times each day, especially before and after meals, physical exercise, and insulin delivery, to be helpful in treating high blood sugar seeFigure 3 [12].

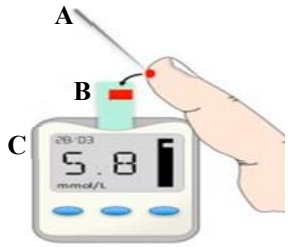

Fig 3: Finger-pricking tool. A lancet needle; B a blood sample on a test strip; and C a glucose meter showing the amount of glucose in mmol/L Adapted from [12].

The three essential parts of a CGM device are a wireless receiver, a transmitter, and a sensor (implantable sensors). The sensor is a small detecting device implanted under the skin. The concentration of glucose in the blood is then calculated using an electrochemical technique [26]. CGM may also contain insulin infusion and management modules, such as an insulin pump [27][28]. Glucose monitoring is commonly performed using either subcutaneously implanted sensors or needle-based glucose metres [29] (see Figure 4).

Blood glucose levels in healthy individuals range from 4.9 to 6.9 mmol/L, but for individuals who have diabetes, they may climb to as high as 40 mmol/L after consuming glucose. When the blood glucose concentration drops below 3.9 mmol/L, a medical condition known as hypoglycemia occurs. Hypoglycemia has a larger risk coefficient among the elderly [30]. Regular monitoring of hypoglycemia at night may be difficult with the current methods of monitoring blood glucose levels. Because of this, strict regulation of blood glucose levels is associated with a higher probability of hypoglycemia. Continuous glucose monitoring (CGM), on the other hand, may have more therapeutic application value and be more in tune with the demands of diabetic customers generally [31].

These techniques have been used for about 50 years, and they have undergone constant development to demand less blood and take measurements more quickly [32]. Unfortunately, the expense, discomfort, blood waste, and calluses associated with this procedure make patients less enthusiastic about performing frequent glucose tests [32][33][34].

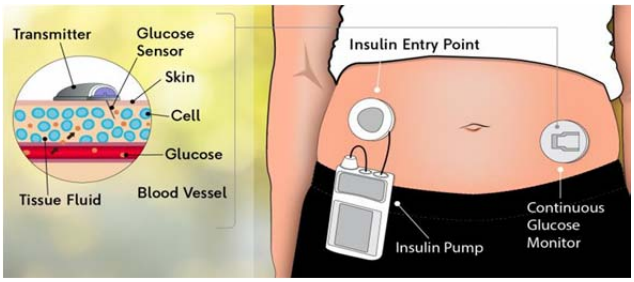

Figure 4. A CGM system consists of transmitter, glucose sensor, and receiver or display Adapted from [25]

Non-Invasive Blood Glucose Monitoring Techniques

Non-invasive (NI) blood glucose monitoring is the measurement of human blood glucose without causing any damage to human tissues. The purpose of NI blood glucose monitoring is to eliminate any discomfort or agony associated with obtaining a glucose measurement [35]. Non-invasive blood glucose monitoring is possible because the glucose molecule may participate in a wide variety of interior physical and chemical processes[36]. Throughout the last several years, the development of non-invasive blood monitoring methods has piqued the interest of both academics and medical equipment makers. If the glucose level recorded by the device varies greatly from the original glucose levels, the patient may be forced to take a high dose of insulin, which might be dangerous [37][38][39]. The precision of these devices is critical in calculating insulin dose. The non-invasive approach may be used to measure glucose at a variety of locations, including the skin, wrist, earlobe, fingertip, and others [34][26].

Non-invasive approaches for measuring blood sugar levels may be roughly classified as microwave [40], electromagnetic [41][42], ultrasound [43], and optical [44][14]. As shown in Figure 1, optical technologies [48][44] include near-infrared [45], far-infrared [46], mid-infrared [47], Raman spectroscopy [14], optical coherence tomography (OCT), and other optical methods. Glucose is found in a variety of bio-fluids, including saliva, tears, sweat, and ISF, in addition to large quantities in human blood [49][48][50][51][52].

These may be classified depending on the glucose sensing technology employed. The major sensing techniques for non-invasive technologies are electrochemical [53][31] and electromagnetic [14][42][54]. In electrochemical noninvasive glucose sensors, a salivary probe [55], tear drops [26], or exhaled breath [56] is evaluated. This is done so that they may be easily collected and accessible. Urine may also be used to assess glucose levels; however, this is not recommended for use with a CGM device [57][58]. As a result, saliva, tears, and exhaled air are advised [55]. These sensors are often known as biosensors [59]. Electromagnetic techniques are utilised based on how electromagnetic waves interact with the human body [52].

It's necessary to use post-processing to establish the relationship between the observed signal from multiple sensing modalities (in most cases, either current, voltage, or phase/frequency) and the blood glucose concentration. The relationship between the recorded signal and the blood glucose level may be established using a simple proportionality formula (BGL). Yet, for reliable BGL extraction, a calibration method is necessary. The pervasive fear of data loss, however, necessitates the use of interpolation and extrapolation [60].Noninvasive blood glucose monitoring technologies have various benefits. The following benefits are stated in the review: less costly, more cost-effective Without pain or suffering There is no need for any more needles. lowest possible health risk, Always double-check, Small size, Simple structure, heightened sensitivity More thorough and trustworthy information, Connectivity to the Internet of Medical Things (IoMT), There are wearable and non-wearable variants. Intelligent implantable medical devices Neural networks with biological interfaces, for example. Remote monitoring is a viable possibility.

Microwave Method

Microwaves are electromagnetic waves with wavelengths ranging from 1 mm to 1 m and frequencies ranging from 300 MHz to 300 GHz [42]. Microwave sensors are often used by scientists in the area of non-invasive blood glucose monitoring because to their great penetrability, absence of ionization, and mobility. They may swiftly penetrate biological tissues a millimeter or more thick, delivering advantages not available with traditional optical detection methods, especially in the low-frequency region. Microwaves, with their lower energy per photon and less air dispersion, may allow for deeper tissue penetration and more precise blood glucose readings [8].

Variations in blood glucose alter the dielectric constant [61] [8][62], which has a significant impact on microwave reflection, transmission, and absorption in tissues. Microwave diagnostics is based on the differentiation between the dielectric properties of healthy and sick tissues [31]. The rise and fall of human blood sugar levels cause only minor variations in dielectric properties, requiring the use of a very sensitive sensor. It is critical to apply the appropriate signal-processing technology in addition to having a multi-frequency resonator with high levels of accuracy and stability [8] [61][63-76].

Electromagnetic Method

Because of its various interactions, including as absorption, scattering, and transmission with specific molecules within the body, electromagnetic (EM) wave sensing has gotten a lot of attention [42][8]. With this approach, interaction of two inductors' magnetic fields is measured by current or voltage [68]. The dielectric properties of blood are measured using eddy current fluctuations as a signal. It entails sending a signal with a certain frequency to the main inductor and receiving a secondary inductor output. This approach does not involve ionisation of bodily components [34].

The tested medium is most responsive to variations in glucose concentration at an appropriate frequency. This technology operates between 2.4 and 2.9 GHz [69]; the device's effectiveness is dependent on the frequency used. The ratio of input to output voltages or currents has a negative correlation with glucose concentration. Also, the frequency of the signal is critical for sufficient coupling, however this is also impacted by sample temperature [70]. It is possible to isolate the influence of blood sugar levels and reduce the effects of potentially confounding components like cholesterol by focusing on a narrow frequency range. It's also quite harmless since it doesn't ionise the body's components [8].

Ultrasound

The time of ultrasonic wave propagation is used to determine the thickness of the material. The faster the glucose concentration, the quicker an ultrasonic wave travels through a medium, the farther it will go.The density of the medium and the strength of the intermolecular bonds within it determine the compressibility of the fluid or tissue, which in turn determines the acoustic velocity of low-frequency waves in the medium [71]. The linear acoustic impedance is affected by factors such as density and adiabatic compressibility, which in turn are affected by changes in the glucose concentration of the extracellular fluid [58].The glucose levels indicated by an optical sensor are extracted using a low-frequency ultrasonic wave [34].

Optical Methods

The technique for developing noninvasive blood glucose detection that has received the most research is optical glucose sensing. There are many techniques that fall under the category of "optical technique," and all of these techniques may determine the amount of glucose in the skin without the use of samples by utilizing light, electric current, etc. [48]. Although cost-effective and comfortable for users, optical approaches are sensitive to environmental factors including temperature, pressure, skin moisture, humidity, and others [48]. For non-invasive blood glucose detections, a variety of optical techniques have been used. Table 1 lists each technique's benefits and drawbacks as well as its basic operating principle.

- **Absorption spectroscopy:** is a method for analysing the characteristics of being absorbed, reflected, and scattered by human tissue by passing near infrared (750 nm–2500 nm), mid-infrared (2500 nm–100,000 nm), or far-infrared light through it. The near infrared spectrum ranges from 750 nm–2500 nm, while the mid–infrared spectrum ranges from 2500 As a result of the interaction between light and tissue and blood, the irradiated light source is absorbed, reflected, and diffused [69] [72-75].
- **Raman spectroscopy:** is a method that takes use of the scattering of light. This is an important part of the method. The scattering phenomenon occurs as a consequence of molecular vibrations and oscillations, which are caused by the shining of a monochromatic laser beam over the sample tissue. Some compounds, like glucose, have degrees of scattering that are wholly dependent on the concentrations of the molecules themselves [69][76-83].
- **Photoacoustic spectroscopy** By using photoacoustic spectroscopy, one may determine the magnitude of the acoustic pressure wave that is generated when laser light is shone on tissues. To create thermal energy from an aqueous glucose solution, an infrared laser is utilised to stimulate the solution, which then absorbs the light. As a direct result of the volumetric expansion that immediately follows, a photoacoustic pressure wave that is associated with glucose level is produced [84][85][8].
- **Thermal Emission Spectroscopy (TES**): employs infrared light emission rather than glucose absorption. The intensity of infrared emission is proportional to the quantity of glucose present in the target location of the body part [86][87][8].
- **Metabolic Heat Conformation:** This involves doing a multivariate mathematical analysis of blood flow rate, blood oxygen saturation level, and heat dissipation. The amount of heat created by glucose oxidation is proportional to the amount of dissipative oxygen and glucose in the body[88][89].
- **Ocular Spectroscopy**: This method places contact lenses made of hydrogel on the patient's eyes. The colour of the lens changes depending on the glucose levels in the blood. These colour changes are employed in order to determine the amount of blood glucose present in the tears of diabetics who are anxious [90][91].
- **Optical Coherence Tomography (OCT):** is a method that uses an ultraluminescent light source, a photo detector, an interferometer that is coupled to the reference arm, and the sample arm. When the incoming laser beam has been backscattered by the tissue complex, the difference in wavelengths of the reflected light from the sample arm and the reference arm may then be calculated. The delay connection is used as a basis for estimating blood glucose levels [69][92][93]
-

Table 1: The test areas, benefits, and limitations of optical blood glucose monitoring techniques.

Optical Technique	Test Area	Benefits	Limitations
Absorption spectroscopy	Earlobe, Palm, Forearm, Inner lip Fingertip	More affordable. Possesses strong tissue penetration.	Low signal-to-noise ratio (SNR), Influenced by the makeup of the tissues.
Fluorescence spectroscopy	Eye, Finger Upper arm, Abdomen.	Sensitive to an extreme degree and needing less calibration.	Depends on the thickness, color, and pigmentation of the skin. The tissue toxicity of the fluorophore dye is possible.
Raman spectroscopy	Wrist, Finger Arm, Eye.	Less susceptible to changes in temperature, moisture, and light interference.	Unstable laser sources, low signal-to-noise ratios, and prolonged spectrum collection times.
Photoacoustic spectroscopy	Arm, Earlobe, Finger	Wider wavelength range of laser light from ultraviolet to near-infrared and better sensitivity.	Susceptible to external influences. susceptible to physiological chemicals' interferences.
Thermal Emission Spectroscopy (TES)		Less calibration is necessary. possesses high repeatability.	Not accurate. influenced by tissue thickness, motion, and temperature.
Metabolic Heat Conformation	Forearm Earlobe Fingertip	Less costly and feasible.	Interference from the surroundings.
Ocular Spectroscopy	Eye	Performed at the cornea of the eye, where light scattering is minimal.	Delay period between glucose levels and tear. The lens causes discomfort for diabetics.
Optical Coherence Tomography (OCT)	Eye, Forearm	Great resolution, strong penetration, and good SNR are its defining characteristics.	Responsive to movement and body temperature.
Optical polarimetry		Independent of changes in temperature and PH. Miniaturization is simple.	Sensitive to movement and the dispersion of tissues. Low glucose molecule specificity.

Optical polarimetry: is a method that measures the effect of optically active solute molecules, such glucose, on the rotation of incident light. This technique was developed in the 1960s. The polarisation of light, which is determined by the temperature, the amount of thickness, and concentration of dissolved substances, is used to quantify the levels of glucose in the blood. It was rubbed into the clear fluid that filled the eyelids [94].

Despite significant advancements and successes in invention of glucose monitors, a number of obstacles persist. Accuracy is a major barrier to the development of blood glucose monitoring technologies. [95][96][97]. Calibration of glucose metres on a regular basis is an additional difficult aspect. Before use, Most methods of noninvasively monitoring blood sugar include taking blood samples and undergoing elaborate calibration processes. Invasive capillary calibration of blood glucose monitors increases cost, pain, and tedious procedures [98].

A poor signal to noise ratio is an additional barrier to the development of noninvasive glucose sensors [99][100][101]. Poor linearity, sensitivity, and selectivity to glucose molecules in noninvasive glucose monitors diminish the signal intensity and precision of glucose measurement. Multisensing might improve the signal-to-noise ratio of glucose concentration estimation [102][103][104]. This model used a variety of non-invasive detection methods. The combination of multisensing with a proper estimation approach improves the accuracy of glucose prediction, according to a research. Artificial neural networks (ANN) are a model of self-calibration that enhances blood glucose monitor calibration [105][106]. As a result of extensive research and technical advancements, the ability to detect and monitor blood glucose levels is growing and becoming more practical. Current innovations in nanotechnology and the miniaturisation of biosensors have allowed the creation of glucose monitoring systems that are more accurate, comprehensive, and dependable.

Conclusion

The methods for determining the glucose levels in the blood must be portable, simple, accurate, low-cost, rapid, and energy-efficient. In addition to these benefits, patients will have a lot simpler time controlling their glucose levels if the therapy is pleasant and does not cause any discomfort. While constructing non-invasive models, it is important to take into account blood-altering illnesses, drugs, dehydration, and other conditions. In recent years, the field of medicine has collaborated with a wide variety of different fields, such as computer science, biology, physics, chemistry, and electrical engineering, to conduct extensive research on improving the reliability and durability of implanted sensors for invasive monitoring. This research has focused on finding ways to make the sensors more long-lasting. Methods of glucose monitoring that do not need invasive surgery and are being developed include those that are more sensitive, pleasant, and portable.

REFERENCES

[1] L. Chen, B. Tuo, and H. Dong, “Regulation of intestinal glucose absorption by ion channels and transporters,” *Nutrients*, vol. 8, no. 1, pp. 1–11, 2016, doi: 10.3390/nu8010043.

[2] M. S. Burhans, D. K. Hagman, J. N. Kuzma, K. A. Schmidt, and M. Kratz, “Contribution of adipose tissue inflammation to the development of type 2 diabetes mellitus,” *Compr. Physiol.*, vol. 9, no. 1, pp. 1–58, 2019, doi: 10.1002/cphy.c170040.

[3] A. Petersmann *et al.*, “Definition, Classification and Diagnosis of Diabetes Mellitus,” *Exp. Clin. Endocrinol. Diabetes*, vol. 126, no. 7, pp. 406–410, 2018, doi: 10.1055/a-0584-6223.

[4] Z. Punthakee, R. Goldenberg, and P. Katz, “Definition, Classification and Diagnosis of Diabetes, Prediabetes and Metabolic Syndrome,” *Can. J. Diabetes*, vol. 42, pp. S10–S15, 2018, doi: 10.1016/j.jcjd.2017.10.003.

[5] J. K. Alwan, D. S. Jaafar, and I. R. Ali, “Diabetes diagnosis system using modified Naive Bayes classifier,” Indones. J. Electr. Eng. Comput. Sci., vol. 28, no. 3, pp. 1766–1774, 2022, doi: 10.11591/ijeecs.v28.i3.pp1766-1774.

[6] D. Care and S. S. Suppl, “Classification and diagnosis of diabetes: Standards of medical care in Diabetesd2018,” *Diabetes Care*, vol. 41, no. January, pp. S13–S27, 2018, doi: 10.2337/dc18-S002.

[7] A. M. Egan and S. F. Dinneen, “What is diabetes?,” *Med. (United Kingdom)*, vol. 47, no. 1, pp. 1–4, 2019, doi: 10.1016/j.mpmed.2018.10.002.

[8] W. V. Gonzales, A. T. Mobashsher, and A. Abbosh, *The progress of glucose monitoring—A review of invasive to minimally and non-invasive techniques, devices and sensors*, vol. 19, no. 4. 2019. doi: 10.3390/s19040800.

[9] S. Nukui *et al.*, “Risk of Hyperglycemia and Hypoglycemia in Patients with Acute Ischemic Stroke Based on Continuous Glucose Monitoring,” *J. Stroke Cerebrovasc. Dis.*, vol. 28, no. 12, p. 104346, 2019, doi: 10.1016/j.jstrokecerebrovasdis.2019.104346.

[10] A. Abu-Samah, N. N. A. Razak, U. K. Jamaludin, F. M. Suhaimi, and A. M. Ralib, “Determination of favorable blood glucose target range for stochastic TARgeted (STAR) glycemic control in Malaysia,” Indones. J. Electr. Eng. Comput. Sci., vol. 15, no. 1, pp. 133–141, 2019, doi: 10.11591/ijeecs.v15.i1.pp133-141.

[11] H. Sun *et al.*, “IDF Diabetes Atlas: Global, regional and country-level diabetes prevalence estimates for 2021 and projections for 2045,” *Diabetes Res. Clin. Pract.*, vol. 183, p. 109119, 2022, doi: 10.1016/j.diabres.2021.109119.

[12] D. Bruen, C. Delaney, L. Florea, and D. Diamond, “Glucose sensing for diabetes monitoring: Recent developments,” *Sensors (Switzerland)*, vol. 17, no. 8, pp. 1–21, 2017, doi: 10.3390/s17081866.

[13] K. E. Toghill and R. G. Compton, “Electrochemical non-enzymatic glucose sensors: A perspective and an evaluation,” *Int. J. Electrochem. Sci.*, vol. 5, no. 9, pp. 1246–1301, 2010.

[14] B. Alsunaidi, M. Althobaiti, M. Tamal, W. Albaker, and I. Al-Naib, “A review of non-invasive optical systems for continuous blood glucose monitoring,” *Sensors*, vol. 21, no. 20, 2021, doi: 10.3390/s21206820.

[15] T. Shang *et al.*, “Products for Monitoring Glucose Levels in the Human Body With Noninvasive Optical, Noninvasive Fluid Sampling, or Minimally Invasive Technologies,” *J. Diabetes Sci. Technol.*, vol. 16, no. 1, pp. 168–214, 2022, doi: 10.1177/19322968211007212.

[16] R. Ajjan, D. Slattery, and E. Wright, “Continuous Glucose Monitoring: A Brief Review for Primary Care Practitioners,” *Adv. Ther.*, vol. 36, no. 3, pp. 579–596, 2019, doi: 10.1007/s12325-019-0870-x.

[17] N. Moodley, U. Ngxamngxa, M. J. Turzyniecka, and T. S. Pillay, “Historical perspectives in clinical pathology: A history of glucose measurement,” *J. Clin. Pathol.*, vol. 68, no. 4, pp. 258–264, 2015, doi: 10.1136/jclinpath-2014-202672.

[18] S. R. Patton and M. A. Clements, “Continuous glucose monitoring versus self-monitoring of blood glucose in children with type 1 diabetes-the pros and cons,” *US Endocrinol.*, vol. 8, no. 1, pp. 27–29, 2012, doi: 10.17925/use.2012.08.01.27.

[19] D. M. Nathan, “The diabetes control and complications trial/epidemiology of diabetes interventions and complications study at 30 years: Overview,” *Diabetes Care*, vol. 37, no. 1, pp. 9–16, 2014, doi: 10.2337/dc13-2112.

[20] M. Care, “Standards of medical care in diabetes-2010,” *Diabetes Care*, vol. 33, no. SUPPL. 1, 2010, doi: 10.2337/dc10-S011.

[21] E. I. Georga, V. C. Protopappas, D. Polyzos, and D. I. Fotiadis, “Evaluation of short-term predictors of glucose concentration in type 1 diabetes combining feature ranking with regression models,” *Med. Biol. Eng. Comput.*, vol. 53, no. 12, pp. 1305–1318, 2015, doi: 10.1007/s11517-015-1263-1.

[22] K. Zarkogianni *et al.*, “Comparative assessment of glucose prediction models for patients with type 1 diabetes mellitus applying sensors for glucose and physical activity monitoring,” *Med. Biol. Eng. Comput.*, vol. 53, no. 12, pp. 1333–1343, 2015, doi: 10.1007/s11517-015-1320-9.

[23] K. M. Bratlie, R. L. York, M. A. Invernale, R. L. Langer, and D. G. Anderson, “Materials for diabetes therapeutics,” *Adv. Healthc. Mater.*, vol. 1, no. 3, pp. 267–284, 2012, doi: 10.1002/adhm.201200037.

[24] A. N. Paradigm, “for a New Paradigm in Testing Glucose,” *Society*, vol. 4, no. 5, pp. 1027–1031, 2010.

[25] S. Kumar Das, K. K. Nayak, P. R. Krishnaswamy, V. Kumar, and N. Bhat, “Review—Electrochemistry and Other Emerging Technologies for Continuous Glucose Monitoring Devices,” *ECS Sensors Plus*, vol. 1, no. 3, p. 031601, 2022, doi: 10.1149/2754-2726/ac7abb.

[26] I. Lee, D. Probst, D. Klonoff, and K. Sode, “Continuous glucose monitoring systems - Current status and future perspectives of the flagship technologies in biosensor research -,” *Biosens. Bioelectron.*, vol. 181, no. February, p. 113054, 2021, doi: 10.1016/j.bios.2021.113054.
[27] R. Mahzabin, F. H. Sifat, S. Anjum, A. A. Nayan, and M. G. Kibria, “Blockchain associated machine learning and IoT based hypoglycemia detection system with auto-injection feature,” Indones. J. Electr. Eng. Comput. Sci., vol. 27, no. 1, pp. 447–455, 2022, doi: 10.11591/ijeecs.v27.i1.pp447-455.
[28] C. Berget, S. Lange, L. Messer, and G. P. Forlenza, “A clinical review of the t:slim X2 insulin pump,” *Expert Opin. Drug Deliv.*, vol. 17, no. 12, pp. 1675–1687, 2020, doi: 10.1080/17425247.2020.1814734.
[29] S. K. Vashist, “Continuous Glucose Monitoring Systems: A Review,” *Diagnostics*, vol. 3, no. 4, pp. 385–412, 2013, doi: 10.3390/diagnostics3040385.
[30] P. Aschner *et al.*, “Global guideline for type 2 diabetes,” *Diabetes Res. Clin. Pract.*, vol. 104, no. 1, pp. 1–52, 2014, doi: 10.1016/j.diabres.2012.10.001.
[31] L. Tang, S. J. Chang, C. J. Chen, and J. T. Liu, “Non-invasive blood glucose monitoring technology: A review,” *Sensors (Switzerland)*, vol. 20, no. 23, pp. 1–32, 2020, doi: 10.3390/s20236925.
[32] P. Moström, E. Ahlén, H. Imberg, P. O. Hansson, and M. Lind, “Adherence of self-monitoring of blood glucose in persons with type 1 diabetes in Sweden,” *BMJ Open Diabetes Res. Care*, vol. 5, no. 1, 2017, doi: 10.1136/bmjdrc-2016-000342.
[33] P. Makaram, D. Owens, and J. Aceros, “Trends in Nanomaterial-Based Non-Invasive Diabetes Sensing Technologies,” *Diagnostics*, vol. 4, no. 2, pp. 27–46, 2014, doi: 10.3390/diagnostics4020027.
[34] K. Ramya, A. Indu, B. Akhila, G. Aswini, and P. B. Babu, “Blood Glucose Monitoring Techniques,” vol. 8, no. 2, pp. 26–32, 2021.
[35] J. Smith, “The Pursuit of Noninvasive Glucose : Hunting the Deceitful Turkey The Pursuit of Noninvasive Glucose : ‘ Hunting the Deceitful Turkey ’ By John L . Smith Copyright 2006 by John L . Smith,” no. January 2006, 2014.
[36] M. Shokrekhodaei and S. Quinones, “Review of non-invasive glucose sensing techniques: Optical, electrical and breath acetone,” *Sensors (Switzerland)*, vol. 20, no. 5, 2020, doi: 10.3390/s20051251.
[37] O. El-Gayar, P. Timsina, N. Nawar, and W. Eid, “A systematic review of IT for diabetes self-management: Are we there yet?,” *Int. J. Med. Inform.*, vol. 82, no. 8, pp. 637–652, 2013, doi: 10.1016/j.ijmedinf.2013.05.006.
[38] Z. Lu *et al.*, “A point of care electrochemical impedance spectroscopy device,” *Int. Syst. Chip Conf.*, vol. 2016-Febru, no. 5 mV, pp. 240–244, 2016, doi: 10.1109/SOCC.2015.7406955.
[39] I. Gouzouasis *et al.*, “Detection of varying glucose concentrations in water solutions using a prototype biomedical device for millimeter-wave non-invasive glucose sensing,” *2016 10th Eur. Conf. Antennas Propagation, EuCAP 2016*, pp. 2–5, 2016, doi: 10.1109/EuCAP.2016.7481921.
[40] M. Baghelani, Z. Abbasi, M. Daneshmand, and P. E. Light, “Non-invasive continuous-time glucose monitoring system using a chipless printable sensor based on split ring microwave resonators,” *Sci. Rep.*, vol. 10, no. 1, pp. 1–15, 2020, doi: 10.1038/s41598-020-69547-1.
[41] J. Hanna *et al.*, “Wearable flexible body matched electromagnetic sensors for personalized non-invasive glucose monitoring,” *Sci. Rep.*, vol. 12, no. 1, pp. 1–12, 2022, doi: 10.1038/s41598-022-19251-z.
[42] R. Zhang *et al.*, “Noninvasive electromagneticwave sensing of glucose,” *Sensors (Switzerland)*, vol. 19, no. 5, 2019, doi: 10.3390/s19051151.
[43] E. Park, J. Baik, H. Kim, S.-M. Park, and C. Kim, “Non-invasive glucose measurement with ultrasound-modulated optical sensing,” no. Mdic, p. 15, 2021, doi: 10.1117/12.2576875.
[44] N. A. Bazaev, Y. P. Masloboev, and S. V. Selishchev, “Optical Methods for Noninvasive Blood Glucose Monitoring,” *Biomed. Eng. (NY).*, vol. 45, no. 6, pp. 229–233, 2012, doi: 10.1007/s10527-012-9249-x.
[45] S. Delbeck, T. Vahlsing, S. Leonhardt, G. Steiner, and H. M. Heise, “Non-invasive monitoring of blood glucose using optical methods for skin spectroscopy—opportunities and recent advances,” *Anal. Bioanal. Chem.*, vol. 411, no. 1, pp. 63–77, 2019, doi: 10.1007/s00216-018-1395-x.
[46] D. C. Klonoff, “Noninvasive blood glucose monitoring,” *Diabetes Care*, vol. 20, no. 3, pp. 433–437, 1997, doi: 10.2337/diacare.20.3.433.
[47] S. Liakat, K. A. Bors, L. Xu, C. M. Woods, J. Doyle, and C. F. Gmachl, “Noninvasive in vivo glucose sensing on human subjects using mid-infrared light,” *Biomed. Opt. Express*, vol. 5, no. 7, p. 2397, 2014, doi: 10.1364/boe.5.002397.
[48] S. A. Siddiqui, Y. Zhang, J. Lloret, H. Song, and Z. Obradovic, “Pain-Free Blood Glucose Monitoring Using Wearable Sensors: Recent Advancements and Future Prospects,” *IEEE Rev. Biomed. Eng.*, vol. 11, no. c, pp. 21–35, 2018, doi: 10.1109/RBME.2018.2822301.
[49] K. Takeuchi and B. Kim, “Functionalized microneedles for continuous glucose monitoring,” *Nano Converg.*, vol. 5, no. 1, 2018, doi: 10.1186/s40580-018-0161-2.
[50] P. Bollella, S. Sharma, A. E. G. Cass, F. Tasca, and R. Antiochia, “Highly Porous Gold Microneedles-Based Biosensor : Characterization and Application in Artificial Interstitial Fluid,” *Catalysts*, vol. 9, no. 580, pp. 1–14, 2019.
[51] F. Ribet, G. Stemme, and N. Roxhed, “Real-time intradermal continuous glucose monitoring using a minimally invasive microneedle-based system,” *Biomed. Microdevices*, vol. 20, no. 4, 2018, doi: 10.1007/s10544-018-0349-6.
[52] Y. Xue, A. S. Thalmayer, S. Zeising, G. Fischer, and M. Lübke, *Commercial and Scientific Solutions for Blood Glucose Monitoring—A Review*, vol. 22, no. 2. 2022. doi: 10.3390/s22020425.
[53] M. H. Hassan, C. Vyas, B. Grieve, and P. Bartolo, “Recent advances in enzymatic and non-enzymatic electrochemical glucose sensing,” *Sensors*, vol. 21, no. 14, 2021, doi: 10.3390/s21144672.
[54] C. G. Juan, B. Potelon, C. Quendo, and E. Bronchalo, “Microwave planar resonant solutions for glucose concentration sensing: A systematic review,” *Appl. Sci.*, vol. 11, no. 15, 2021, doi: 10.3390/app11157018.
[55] M. Zhao and P. S. Leung, “Revisiting the use of biological fluids for noninvasive glucose detection,” *Future Med. Chem.*, vol. 12, no. 8, pp. 645–647, 2020, doi: 10.4155/fmc-2020-0019.
[56] K. Dixit, S. Fardindoost, A. Ravishankara, N. Tasnim, and M. Hoorfar, “Exhaled breath analysis for diabetes diagnosis and monitoring: Relevance, challenges and possibilities,” *Biosensors*, vol. 11, no. 12, 2021, doi: 10.3390/bios11120476.
[57] M. Mohammadifar, M. Tahernia, and S. Choi, “An Equipment-Free, Paper-Based Electrochemical Sensor for Visual Monitoring of Glucose Levels in Urine,” *SLAS Technol.*, vol. 24, no. 5, pp. 499–505, 2019, doi: 10.1177/2472630319846876.
[58] J. Zhang, J. Liu, H. Su, F. Sun, Z. Lu, and A. Su, “A wearable self-powered biosensor system integrated with diaper for detecting the urine glucose of diabetic patients,” *Sensors Actuators, B Chem.*, vol. 341, no. April, p. 130046, 2021, doi: 10.1016/j.snb.2021.130046.
[59] Y. Zhang, J. Sun, L. Liu, and H. Qiao, “A review of biosensor technology and algorithms for glucose monitoring,” *J. Diabetes Complications*, vol. 35, no. 8, p. 107929, 2021, doi: 10.1016/j.jdiacomp.2021.107929.
[60] X. Xiao, Q. Yu, Q. Li, H. Song, and T. Kikkawa, “Precise Noninvasive Estimation of Glucose Using UWB Microwave with Improved Neural Networks and Hybrid Optimization,” *IEEE Trans. Instrum. Meas.*, vol. 70, no. c, 2021, doi: 10.1109/TIM.2020.3010680.
[61] V. Turgul and I. Kale, “Simulating the Effects of Skin Thickness and Fingerprints to Highlight Problems with Non-Invasive RF Blood Glucose Sensing from Fingertips,” *IEEE Sens. J.*, vol. 17, no. 22, pp. 7553–7560, 2017, doi: 10.1109/JSEN.2017.2757083.
[62] M. Hofmann, G. Fischer, R. Weigel, and D. Kissinger, “Microwave-based noninvasive concentration measurements for biomedical applications,” *IEEE Trans. Microw. Theory Tech.*, vol. 61, no. 5, pp. 2195–2204, 2013, doi: 10.1109/TMTT.2013.2250516.
[63] H. Choi *et al.*, “Design and in Vitro Interference Test of Microwave Noninvasive Blood Glucose Monitoring Sensor,” *IEEE Trans. Microw. Theory Tech.*, vol. 63, no. 10, pp. 3016–3025, 2015, doi: 10.1109/TMTT.2015.2472019.
[64] A. E. Omer, S. Gigoyan, G. Shaker, and S. Safavi-Naeini, “WGM-Based Sensing of Characterized Glucose- Aqueous Solutions at mm-Waves,” *IEEE Access*, vol. 8, pp. 38809–38825, 2020, doi: 10.1109/ACCESS.2020.2975805.
[65] J. Vrba, J. Karch, and D. Vrba, “Phantoms for development of microwave sensors for noninvasive blood glucose monitoring,” *Int. J. Antennas Propag.*, vol. 2015, 2015, doi: 10.1155/2015/570870.
[66] S. Kim *et al.*, “Noninvasive in vitro measurement of pig-blood d-glucose by using a microwave cavity sensor,” *Diabetes Res. Clin. Pract.*, vol. 96, no. 3, pp. 379–384, 2012, doi: 10.1016/j.diabres.2012.01.018.
[67] R. Narang *et al.*, “Sensitive, Real-time and Non-Intrusive Detection of Concentration and Growth of Pathogenic Bacteria using Microfluidic-Microwave Ring Resonator Biosensor,” *Sci. Rep.*, vol. 8, no. 1, pp. 1–10, 2018, doi: 10.1038/s41598-018-34001-w.
[68] A. Tura, S. Sbrignadello, D. Cianciavicchia, G. Pacini, and P. Ravazzani, “A low frequency electromagnetic sensor for indirect measurement of glucose concentration: In vitro experiments in different conductive solutions,” *Sensors*, vol. 10, no. 6, pp. 5346–

5358, 2010, doi: 10.3390/s100605346.
[69] J. Chung, H. So, Choi, and T. K. S. Wong, “Recent advances in noninvasive glucose monitoring,” *Med. Devices Evid. Res.*, p. 45, 2012, doi: 10.2147/mder.s28134.
[70] M. Gourzi *et al.*, “Non-invasive glycaemia blood measurements by electromagnetic sensor: Study in static and dynamic blood circulation,” *J. Med. Eng. Technol.*, vol. 29, no. 1, pp. 22–26, 2005, doi: 10.1080/03091900410001720247.
[71] I. Harman-Boehm, A. Gal, A. M. Raykhman, J. D. Zahn, E. Naidis, and Y. Mayzel, “Noninvasive glucose monitoring: A novel approach,” *J. Diabetes Sci. Technol.*, vol. 3, no. 2, pp. 253–260, 2009, doi: 10.1177/193229680900300205.
[72] J. Yadav, A. Rani, V. Singh, and B. M. Murari, “Prospects and limitations of non-invasive blood glucose monitoring using near-infrared spectroscopy,” *Biomed. Signal Process. Control*, vol. 18, pp. 214–227, 2015, doi: 10.1016/j.bspc.2015.01.005.
[73] G. Han, S. Chen, X. Wang, J. Wang, H. Wang, and Z. Zhao, “Noninvasive blood glucose sensing by near-infrared spectroscopy based on PLSR combines SAE deep neural network approach,” *Infrared Phys. Technol.*, vol. 113, no. December 2020, p. 103620, 2021, doi: 10.1016/j.infrared.2020.103620.
[74] P. Jain, R. Maddila, and A. M. Joshi, “A precise non-invasive blood glucose measurement system using NIR spectroscopy and Huber’s regression model,” *Opt. Quantum Electron.*, vol. 51, no. 2, pp. 1–15, 2019, doi: 10.1007/s11082-019-1766-3.
[75] S. S. Mohammed Sheet and M. S. Jarjees, “Microcontroller based in vitro hematocrit measurement system,” Indones. J. Electr. Eng. Comput. Sci., vol. 18, no. 2, pp. 717–723, 2020, doi: 10.11591/ijeecs.v18.i2.pp717-723.
[76] M. Aloraefy, T. Joshua Pfefer, J. C. Ramella-Roman, and K. E. Sapsford, “In vitro evaluation of fluorescence glucose biosensor response,” *Sensors (Switzerland)*, vol. 14, no. 7, pp. 12127–12148, 2014, doi: 10.3390/s140712127.
[77] H. Zhai, Y. Bai, J. Qin, and F. Feng, “Colorimetric and ratiometric fluorescence dual-mode sensing of glucose based on carbon quantum dots and potential UV/fluorescence of o-diaminobenzene,” *Sensors (Switzerland)*, vol. 19, no. 3, 2019, doi: 10.3390/s19030674.
[78] M. J. Cho and S. Y. Park, “Carbon-dot-based ratiometric fluorescence glucose biosensor,” *Sensors Actuators, B Chem.*, vol. 282, pp. 719–729, 2019, doi: 10.1016/j.snb.2018.11.055.
[79] D. C. Klonoff, “Overview of fluorescence glucose sensing: A technology with a bright future,” *J. Diabetes Sci. Technol.*, vol. 6, no. 6, pp. 1242–1250, 2012, doi: 10.1177/193229681200600602.
[80] R. Pandey *et al.*, “Noninvasive Monitoring of Blood Glucose with Raman Spectroscopy,” *Acc. Chem. Res.*, vol. 50, no. 2, pp. 264–272, 2017, doi: 10.1021/acs.accounts.6b00472.
[81] N. B. Davison, C. J. Gaffney, J. G. Kerns, and Q. D. Zhuang, “Recent Progress and Perspectives on Non-Invasive Glucose Sensors,” *Diabetology*, vol. 3, no. 1, pp. 56–71, 2022, doi: 10.3390/diabetology3010005.
[82] J. W. Kang *et al.*, “Direct observation of glucose fingerprint using in vivo Raman spectroscopy,” *Sci. Adv.*, vol. 6, no. 4, pp. 2–10, 2020, doi: 10.1126/sciadv.aay5206.
[83] D. R. Parachalil, J. McIntyre, and H. J. Byrne, “Potential of Raman spectroscopy for the analysis of plasma/serum in the liquid state: recent advances,” *Anal. Bioanal. Chem.*, vol. 412, no. 9, pp. 1993–2007, 2020, doi: 10.1007/s00216-019-02349-1.
[84] Y. Jin, Y. Yin, C. Li, H. Liu, and J. Shi, “Non-Invasive Monitoring of Human Health by Photoacoustic Spectroscopy,” *Sensors*, vol. 22, no. 3, pp. 1–14, 2022, doi: 10.3390/s22031155.
[85] Y. Tanaka, T. Tajima, M. Seyama, and K. Waki, “Differential Continuous Wave Photoacoustic Spectroscopy for Non-Invasive Glucose Monitoring,” *IEEE Sens. J.*, vol. 20, no. 8, pp. 4453–4458, 2020, doi: 10.1109/JSEN.2019.2962251.
[86] N. A. B. A. Salam, W. H. B. M. Saad, Z. B. Manap, and F. Bte Salehuddin, “The evolution of non-invasive blood glucose monitoring system for personal application,” *J. Telecommun. Electron. Comput. Eng.*, vol. 8, no. 1, pp. 59–65, 2016.
[87] I. Osiecka and T. Pałko, “Overview of some non-invasive spectroscopic methods of glucose level monitoring,” *Acta Bio-Optica Inform. Medica. Inz. Biomed.*, vol. 22, no. 1, pp. 1–8, 2016, [Online]. Available: https://www.infona.pl/resource/bwmeta1.element.baztech-0da018fd-b2ae-4dd6-b9c3-95e925c4ab3b
[88] T. Fei, W. Xiaohao, W. Dongsheng, and L. Junfeng, “Non-invasive glucose measurement by use of metabolic heat conformation method,” *Sensors*, vol. 8, no. 5, pp. 3335–3344, 2008, doi: 10.3390/s8053335.
[89] R. Takeuchi, K. Nagao, and H. Miyamoto, “Non-Invasive Diabetes Prediction Method Based on Metabolic Heat Conformation Theory and Machine Learning,” *J. Mech. Electr. Intell. Syst. J. Mech. Elect. Intel. Syst*, vol. 4, no. 1, pp. 42–49, 2021, [Online]. Available: http://jmeis.e-jikei.org/ARCHIVES/v04n01/JMEIS_v04n01a005.pdf
[90] A. Srivastava, M. K. Chowdhury, S. Sharma, and N. Sharma, “Blood Glucose Monitoring Using Non Invasive Optical Method: Design Limitations and Challenges,” *Int. J. Adv. Res. Electr. Electron. Instrum. Eng.*, vol. 2, no. 1, pp. 615–620, 2013, [Online]. Available: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1089.7890&rep=rep1&type=pdf%0Awww.ijareeie.com
[91] S. Jang, “Review of Emerging Approaches in Non- or Minimally Invasive Glucose Monitoring and their Application to Physiological Human Body Fluids,” *Int. J. Biosens. Bioelectron.*, vol. 4, no. 2, 2018, doi: 10.15406/ijbsbe.2018.04.00087.
[92] R. A. Gabbay and S. Sivarajah, “Optical coherence tomography-based continuous noninvasive glucose monitoring in patients with diabetes,” *Diabetes Technol. Ther.*, vol. 10, no. 3, pp. 188–193, 2008, doi: 10.1089/dia.2007.0277.
[93] R. He, “Effects of optical clearing agents on noninvasive blood glucose monitoring with optical coherence tomography: a pilot study,” *J. Biomed. Opt.*, vol. 17, no. 10, p. 101513, 2012, doi: 10.1117/1.jbo.17.10.101513.
[94] J. Yadav, A. Rani, V. Singh, and B. M. Murari, “Comparative Study of Different Measurement Sites Using NIR Based Non-invasive Glucose Measurement System,” *Procedia Comput. Sci.*, vol. 70, pp. 469–475, 2015, doi: 10.1016/j.procs.2015.10.082.
[95] X. Li and C. Li, “Research on non-invasive glucose concentration measurement by NIR transmission,” *Proc. 2015 IEEE Int. Conf. Comput. Commun. ICCC 2015*, pp. 223–228, 2016, doi: 10.1109/CompComm.2015.7387571.
[96] K. Aishwarya Lakshmi, R. Rashmi, S. Sadanand, C. K. Narayanappa, and N. Sriram, “Studies on relating to monitoring blood glucose levels using non-invasive optical methods,” *RTEICT 2017 - 2nd IEEE Int. Conf. Recent Trends Electron. Inf. Commun. Technol. Proc.*, vol. 2018-Janua, pp. 2111–2113, 2017, doi: 10.1109/RTEICT.2017.8256972.
[97] J. D. Campbell, “Development of non-invasive , optical methods for central cardiovascular monitoring,” no. Cvd, 2022.
[98] J. L. Hammond, N. Formisano, P. Estrela, S. Carrara, and J. Tkac, “Electrochemical biosensors and nanobiosensors,” *Essays Biochem.*, vol. 60, no. 1, pp. 69–80, 2016, doi: 10.1042/EBC20150008.
[99] B. Paul, M. P. Manuel, and Z. C. Alex, “Design and development of non invasive glucose measurement system,” *Proc. - ISPTS-1, 1st Int. Symp. Phys. Technol. Sensors*, pp. 43–46, 2012, doi: 10.1109/ISPTS.2012.6260873.
[100] Z. Li, G. Li, W. J. Yan, and L. Lin, “Classification of diabetes and measurement of blood glucose concentration noninvasively using near infrared spectroscopy,” *Infrared Phys. Technol.*, vol. 67, pp. 574–582, 2014, doi: 10.1016/j.infrared.2014.09.040.
[101] B. Javid, F. G. Faranak, and F. S. Zakeri, “Noninvasive optical diagnostic techniques for mobile blood glucose and bilirubin monitoring,” *J. Med. Signals Sens.*, vol. 8, no. 3, pp. 125–139, 2018, doi: 10.4103/jmss.JMSS-8-18.
[102] P. P. Pai, P. Kumar Sanki, A. De, and S. Banerjee, “NIR photoacoustic spectroscopy for non-invasive glucose measurement,” *Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBS*, vol. 2015-Novem, pp. 7978–7981, 2015, doi: 10.1109/EMBC.2015.7320243.
[103] A. Asaduzzaman, S. Samadarsinee, and K. K. Chidella, “Simulating multisensor noninvasive blood glucose monitoring systems,” *Conf. Proc. - IEEE SOUTHEASTCON*, vol. 2016-July, 2016, doi: 10.1109/SECON.2016.7506765.
[104] L. N. Bachache, J. A. Hasan, and A. Q. Al-Neami, “Acousto-optic Design to Measure Glucose Level for Diabetic Patients Non-invasively,” *J. Phys. Conf. Ser.*, vol. 1818, no. 1, pp. 0–17, 2021, doi: 10.1088/1742-6596/1818/1/012147.
[105] J. Yadav, A. Rani, V. Singh, and B. M. Murari, “Levenberg–Marquardt-Based Non-Invasive Blood Glucose Measurement System,” *IETE J. Res.*, vol. 64, no. 1, pp. 116–123, 2018, doi: 10.1080/03772063.2017.1351313.
[106] C. Tronstad *et al.*, “Non-invasive prediction of blood glucose trends during hypoglycemia,” *Anal. Chim. Acta*, vol. 1052, pp. 37–48, 2019, doi: 10.1016/j.aca.2018.12.009.