Journal of Technology Research (JTR)
Volume 5, Issue 1, (2025), pp 011-022, ISSN 3005-639X

Innovative Solutions for Glucose Monitoring: A Non-Invasive Approach for Diabetes Management Review

Shada Elwefati*[1], Hamza Swehli[1], Leenah Hudoud[1], Lina Drebi[1], Rahaf Shifshah[1], Tagiwa Abusetta[1]

[1]Department of Biomedical Engineering, Faculty of Engineering, University of Tripoli, Tripoli, Libya.
*Corresponding author email: s.elwefati@uot.edu.ly.

Received: 02-05-2025| Accepted: 27-05-2025 | Available online: 01-06-2025 | DOI:10.26629/jtr.2025.02

ABSTRACT

This review explores a pioneering technique for measuring glucose levels, addressing a critical need for millions, especially diabetics. Conventional methods, which rely on painful and potentially dangerous blood tests, have long been a daily challenge, particularly for children and individuals with specific blood conditions. In contrast, the technique we introduce offers a ground-breaking, pain-free solution by measuring glucose levels from saliva. By establishing a reliable correlation between salivary and blood glucose, this approach offers a game-changing way to monitor glucose levels with ease and accuracy, revolutionizing diabetes care. The device employs advanced enzyme-based biofluid sensors, providing precise and efficient glucose measurements without the need for invasive procedures. Beyond real-time glucose analysis, the system goes a step further by storing critical data and generating detailed monthly reports, accessible through a dedicated smartphone application. This feature empowers patients to monitor their health continuously, facilitating seamless communication with healthcare providers and enabling personalized care. Furthermore, we present a robust mathematical model and simulation, which demonstrates the relationship between blood and saliva glucose levels through nonlinear equations. The device's performance is validated by comparing simulation results developed using MATLAB and Simulink with analytical solutions, offering deeper insights into its functionality and This represents a revolution in oral diagnosis of diabetes. This innovative approach can reshape diabetes mellitus management by providing a non-invasive, accurate,andpatient-friendly alternative to traditional blood glucose testing. The advancements discussed in this paper signal a promising future in glucose monitoring improving the lives of diabetics and offering new hope in the ongoing battle against diabetes.

Keywords: Glucose levels, Salivary, Blood glucose, Advanced enzyme, Biofluid sensors.

حلول مبتكرة لمراقبة الجلوكوز: مراجعة بأسلوب غير جراحي لإدارة مرض السكري

شذى الويفاتي[1]، حمزة السويحلي[1]، لينة حدود[1]، لينا دريبي[1]، رهف محمد[1]، تقوى أبوسته[1]

[1] قسم الهندسة الطبية الحيوية، كلية الهندسة، جامعة طرابلس، طرابلس

ملخـــــــص البحـــــــث

ستعرض هذه المراجعة تقنية رائدة لقياس مستويات الجلوكوز، تلبي حاجة أساسية لملايين الأشخاص، وخاصة مرضى السكري. فالطرق التقليدية، التي تعتمد على اختبارات الدم المؤلمة والتي قد تنطوي على مخاطر، ظلت تمثل تحديًا يوميًا كبيرًا، خصوصًا للأطفال وللأشخاص الذين يعانون من حالات دموية خاصة. في المقابل، تقدم التقنية المطروحة حلاً مبتكرًا وخاليًا من الألم من خلال قياس مستويات الجلوكوز في اللعاب. ومن خلال إثبات وجود ارتباط موثوق بين مستويات الجلوكوز في اللعاب والدم، يوفر هذا النهج وسيلة ثورية لمراقبة الجلوكوز بسهولة ودقة، مما يحدث نقلة نوعية في رعاية

مرضى السكري. يعتمد الجهاز على مجسات حيوية متقدمة قائمة على الإنزيمات، تتيح قياسات دقيقة وفعّالة للجلوكوز دون الحاجة لإجراءات تدخلية. وإلى جانب التحليل الفوري لمستوى الجلوكوز، يتميز النظام بقدرته على تخزين البيانات المهمة وإصدار تقارير شهرية مفصلة، يمكن الوصول إليها عبر تطبيق مخصص للهواتف الذكية، الأمر الذي يمكّن المرضى من متابعة صحتهم باستمرار ويُسهل التواصل مع مقدمي الرعاية الصحية لتقديم رعاية شخصية. بالإضافة إلى ذلك، يعرض البحث نموذجًا رياضيًا متينًا ومحاكاة تبيّن العلاقة بين مستويات الجلوكوز في الدم واللعاب من خلال معادلات غير خطية. وقد جرى التحقق من أداء الجهاز بمقارنة نتائج المحاكاة، المطوّرة باستخدام **MATLAB** و **Simulink**، مع الحلول التحليلية، مما يعمّق فهم وظائفه. ويمثل هذا ثورة في مجال التشخيص الفموي لمرض السكري. إن هذا النهج المبتكر يعيد تشكيل إدارة مرض السكري من خلال توفير بديل غير تدخلي، دقيق، وسهل الاستخدام لاختبارات الدم التقليدية. وتشير التطورات الواردة في هذه الورقة إلى مستقبل واعد في مراقبة الجلوكوز، ما يسهم في تحسين حياة مرضى السكري ومنحهم أملًا جديدًا في مواجهة هذا المرض.

الكلمات الدالة: مستويات الجلوكوز، اللعاب، جلوكوز الدم، الإنزيمات المتقدمة، المجسات الحيوية للسوائل.

1. INTRODUCTION

1.1 Overview of Diabetes

Diabetes mellitus is a chronic condition by evaluated blood glucose levels due to a deficiency of insulin production or the body's reaction to it, so it is classified into two primary types: the body lacks insulin (Type-1) and the cells become resistant to insulin (Type-2) [1]. Neglected diabetes can lead to serious health complications, including issues with the heart, nerves, kidneys, and vision [2]. In the past few years, there has been increasing interest in exploring the correlation between blood glucose levels and salivary glucose in diabetic individuals [3]. This interest derives from the potential to find a minimally invasive method for monitoring blood glucose. In a by Yang yang Cui and his colleagues (2022) found that unstimulated salivary glucose salivary from the parotid gland shows a higher correlation with blood glucose level, improving the potential applications of saliva as a non-invasive alternative for diabetes monitoring [4].

Blood samples are the benchmark for laboratory diagnostic tests; however, this test requires frequent blood draw, which can cause inconvenience and apprehension among patients [5-7]. Saliva offers some distinctive advantages. Whole saliva can be collected non-invasively and by individuals with limited training. No special equipment is needed for the collection of the fluid. Diagnosis of disease via the analysis of saliva is potentially valuable for children and older adults [3][8].

However, variations in salivary glucose measurements results can arise depending on sample collection methods, Emphasizing the urgent need for further research in this area [9]. Despite existing studies, gaps remain in understanding how several factors influence the accuracy of salivary glucose measurements [10]. Addressing these gaps is crucial for validating saliva tests as a reliable alternative for diabetes diagnostic [11]. This review aims to compile and summarize the current literature on this topic, providing new insights to enhance the use of saliva as an effective diagnostic tool for diabetes [9][12].

2. MATERIAL AND METHODS

2.1 Study population

Diabetes has a high incidence rate, numerous complications, wide pathogenic factors, difficulty in curing and causes other serious hazards to human health. Therefore, many related fields have been actively devoted to the research of diabetes [13-14]. According to the World Health Organization (WHO), currently there are around 860 thousand cases of diabetes in Libya which represents 13.7% of population in the country in 2016, Diabetes accounts for 5% of deaths in the country.[15] and According to the International Diabetes Federation (IDF), currently there are around 399 thousand Total cases of diabetes in adults in Libya in 2021 [16].

2.2 Monitoring Glucose Concentration

General purpose: To measure the amount of glucose in the sample [17-19].

Basic reaction:

$$\text{Glucose} + O_2 \rightarrow \text{gluconic acid} + H_2O_2 \quad (1)$$

This is the basic reaction. Glucose (sugar) reacts with oxygen (O_2) in the presence of an enzyme called glucose oxidase (GOx). This reaction produces gluconic acid and hydrogen peroxide (H_2O_2) [20-21].

2.3 How the sensor works

A. Enzyme (GOx): The sensor uses the enzyme glucose oxidase. This enzyme is extremely specific to glucose, meaning it only reacts with glucose [22].

B. Electrode preparation: The sensor has electrodes (WE - working electrode, CE - counter electrode, RE - reference electrode) connected to a potentiometer (an electronic device that controls the voltage between the electrodes). The working electrode (WE) is coated with an ENFM (electrospun nanofiber membrane) containing the GOx enzyme [23].

C. Reaction at the working electrode: When glucose is present, the reaction (Glucose + O_2 → Gluconic acid + H_2O_2) occurs at the working electrode. This reaction produces hydrogen peroxide (H_2O_2) [24].

D. Measurement of H_2O_2: The entire operation of this device is based on this compound, which is that the hydrogen peroxide (H_2O_2) product is electrochemically active. This means that it can be oxidized (losing electrons) on the surface of the electrode. As we know, this oxidation (loss of electrons) generates an exceedingly small electric current that can be measured by voltage [21].

E. Linking current to glucose: The amount of current generated is directly proportional to the amount of hydrogen peroxide produced, which in turn is directly proportional to the amount of glucose present. So, by measuring the current, the sensor can determine the concentration of glucose in the sample. This process may seem a bit long and detailed, but it accurately quantifies the amount of glucose and is the same mechanism by which blood glucose has been measured for years as a reference standard [25].

2.4 Technical Illustration

The image below is shown in Fig. 1. shows the relationship between the design of the electrochemical glucose sensor using electrospun nanofibrous membranes (ENFM) and its mechanism of operation [26]. The diagram demonstrates the chemical reactions, where glucose reacts with oxygen to form gluconic acid and hydrogen peroxide. This reaction generates an electrochemical signal that is measured by the electrodes [27].

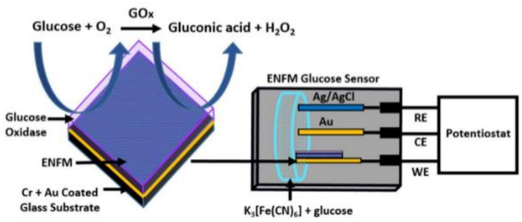

Fig.1. Diagram of relationship between the design of the electrochemical glucose sensor using (ENFM).

According to whether the blood glucose test has caused injury to human skin, it can be simply divided into invasive and non-invasive glucose monitoring [25-28]

2.4 Invasive Monitoring: Blood Glucose Test

Blood glucose test strips employ a dried reagent layer containing a cascade of biochemicals, including enzymes, coenzymes, mediators, and indicators such as COx [29]. Upon contact with blood, these reagents catalyze a series of reactions, generating an electrical signal proportional to the blood glucose concentration. This signal is then processed by a handheld meter [27]. Key performance parameters such as speed, specificity, accuracy, and precision are critically determined by the strip's chemical composition and design. Recent decades have witnessed significant advancements, with modern strips achieving results within 5 seconds using minute blood volumes (≤ 1 μL) [30].

2.5 Non-Invasive Monitoring: Saliva Glucose Test

Saliva glucose test strips utilize a specialized reagent layer containing various biochemicals, including enzymes, coenzymes, mediators, and indicators [31]. When saliva meets these reagents, they catalyze a series of chemical reactions that produce an electrical signal, which is directly proportional to the glucose concentration in the saliva. This signal is then processed by a handheld device or connected application. The performance of the test, including its speed, specificity, accuracy, and precision, is largely determined by the chemical composition and design of the strip [20-22]. Recent developments in this technology have led to improvements in testing time and accuracy, with modern saliva glucose tests providing results in just a few seconds, even with very small saliva samples [8][32].

3. SALIVA GLUCOSE SENSORS

These sensors work by detecting the concentration of glucose in saliva using biochemical reagents that react to the glucose, generating an electrical signal. This signal is then processed and displayed on a device, offering real-time glucose monitoring. Saliva collection for glucose testing is simple and pain-free, requiring just a small sample of saliva, making it an attractive option for continuous glucose monitoring and diabetes management.

Saliva was collected in different conditions fasting, post meal or random each participant rinsed with and swallowed 15 mL of water before saliva collection [33-34].

Disposable Test Strip with Enzyme Reaction: This system utilizes a disposable test strip with three key components [35-37]:

1. Saliva collection area.
2. Flow channel.
3. Reaction area (containing glucose dehydrogenase enzyme and electrodes).

When saliva interacts with the enzyme in the reaction area, a chemical reaction occurs, generating an electrical current [38]. This current is then measured and converted into a digital blood glucose reading [39].Important methods aim to provide more convenient and less painful alternatives to traditional finger-prick blood glucose monitoring [40-43].

3.1 Potential Advantages

- Ease of Use: aim for user-friendly operation, potentially allowing patients to perform self-tests.
- Painless: Eliminating the need for finger pricks significantly improves patient comfort.
- Faster Results: Saliva-based tests may offer quicker results compared to some traditional methods.
- (Test Strip): Emphasizes simplicity and disposability for convenient single-use testing.

3.2 Further Considerations

Requires thorough validation and clinical trials to establish its accuracy and reliability in real-world settings [44-49].

3.3 Refined Method (Test Strip)

- Saliva Collection: The user collects a saliva sample using the designated area on the test strip [50].

- Sample Transport: The saliva sample flows through the channel to the reaction area.
- Enzyme Reaction: In the reaction area, glucose in the saliva reacts with the immobilized glucose dehydrogenase enzyme [51].
- Electrochemical Signal: The enzymatic reaction generates an electrical current.
- Signal Detection: Electrodes within the reaction area detect and measure the electrical current [52].
- Data Processing: The measured current is processed by a device (e.g., a handheld reader) to determine the blood glucose level.
- Result Display: The device displays the calculated blood glucose level to the user [53-55].

4. BMEERS MODEL

4.1 BMEERS simulator

In this section, the medical device for saliva-based glucose level (SGL) monitoring using BMEERS Based on (Biomedical Engin EERS simulator), which was modeled and simulated using Simulink, is discussed.

The device's effectiveness and the accuracy of its results are evaluated through a series of simulations. The primary goal of the device is to offer a non-invasive, reliable method for monitoring glucose levels, which is a significant advancement over traditional blood glucose measurement techniques.

The BMEERS model of the device it consists of two main parts:

1- First part is a simulation of the salivary biosensor strip used to measure the concentration of glucose in saliva as shown in Fig. 2.

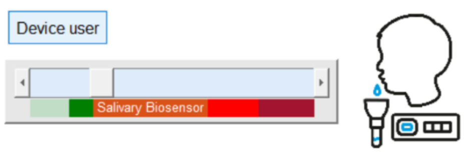

Fig. 2. Salivary biosensor strip

2 – Second part is a simulation of the part designated to show the result, analyze it and send it to the smartphone to store it in the dedicated application. Also, this part consists of an LCD screen showing the time, the hour, the result of the analysis and the unit of measurement in addition to a small message indicating whether the glucose level is low, normal, high or dangerous as shown in Fig. 3.

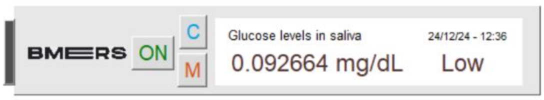

Fig. 3. BMEERS simulator

Furthermore, it has three buttons as shown in Fig.4.

ON: to open, C: to clear all results or reset, and M: used to store the result for review, monitoring, or comparison after a period.

Fig. 4. BMEERS buttons.

Additionally, there is a side button designated for closing. The BMEERS device app stores the user's results with date and time and allows calling emergency services or registered numbers if the reading is dangerous as shown in Fig 5.

4.2 BMEERS Mobile Application

Mobile application is to monitor glucose levels in real time. In addition to continuous monitoring, the application includes an emergency feature that can contact emergency services or notify a designated relative in case of critical glucose levels as shown in Fig. 6.

The app also offers a pharmacy locator feature, enabling users to search for nearby pharmacies and find locations where necessary medications are available. This feature aims to provide users with quick access to vital resources during emergencies.

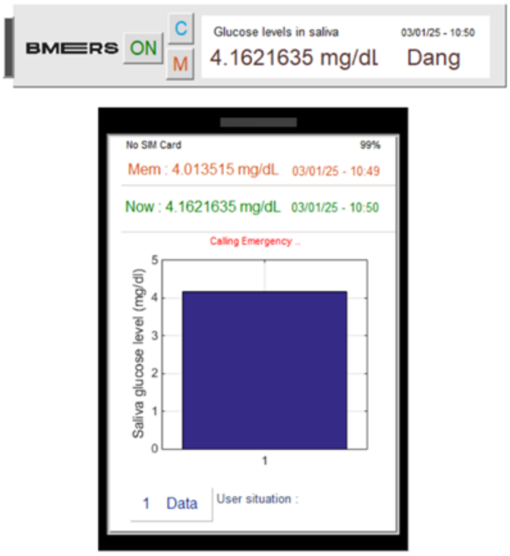

Fig. 5. BMEERS Device mobile app (mg/dl)

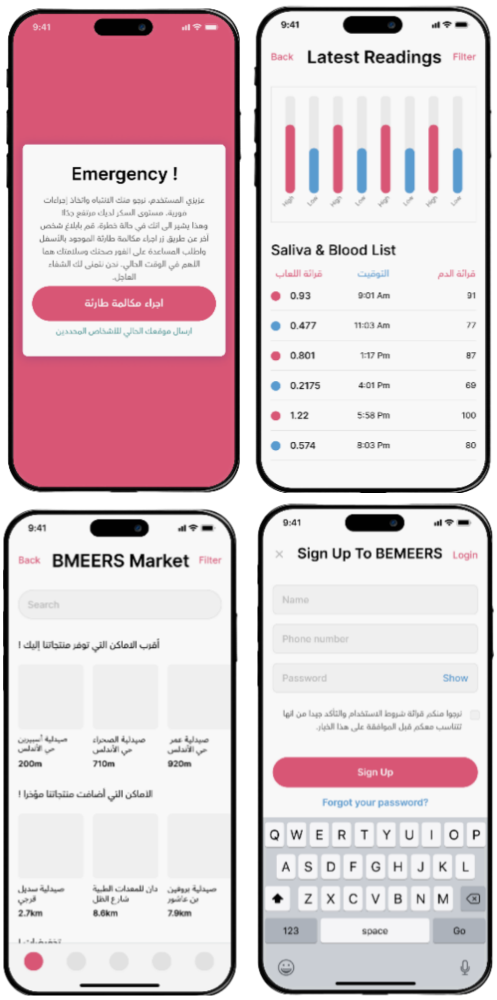

Fig. 6. BMEERS mobile application user interface

5. SIMULATION RESULTS

5.1 BMEERS Device Performance results

The simulation results demonstrate that the saliva-based glucose level monitoring system accurately reflects the changes in glucose concentration within the biological system. The device's output shows a high correlation with the expected physiological glucose values, confirming its potential for accurate real-time monitoring. Through various test scenarios, the model has been proven to maintain a minimal margin of error, ensuring its practical applicability in real-world settings.

5.2 Visual Representation of Data

The glucose readings are shown as bars on the mobile screen, each bar representing one reading, making it easier for the user to quickly observe fluctuations in glucose levels. This bar chart format provides a straightforward way to assess glucose levels at specific times, offering a visual overview of the data as shown in Fig. 7.

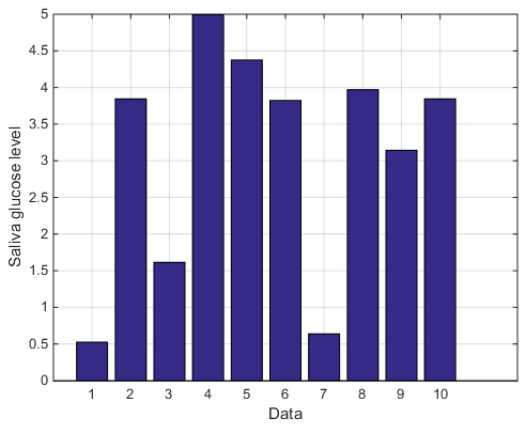

Fig. 7. Bar chart showing the Saliva Glucose construction Data result (mg/dl).

Additionally, Fig. 8, showing glucose levels over a week represented as a continuous curve (line graph) to better visualize the trends and fluctuations over a longer period. For instance, over the course of a week.

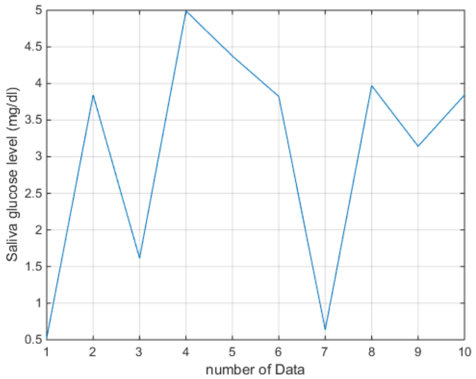

Fig. 8. Glucose levels over a week curve,

This can be particularly useful for people with conditions like diabetes, as it allows them to monitor their glucose levels regularly and identify any patterns, such as spikes or drops, which could indicate the need for dietary adjustments or medication.

The simulation results highlight the effectiveness of the saliva-based glucose measurement device as a user-friendly and efficient method for monitoring glucose levels. The data, displayed in bar chart and curve graph formats, enables a comprehensive analysis of glucose trends, enhancing user experience and aiding in better glucose management.

5.3 Comparative between BGL and SGL

This part of the simulation compares the performance of the saliva-based device with a traditional blood glucose level (BGL) monitoring system. The simulated data indicates that while there are some differences between the two methods, the saliva device closely tracks the blood glucose readings, with the divergence being within an acceptable range for medical applications.

In this study, we compared two glucose measurement methods: a saliva-based device and a traditional blood glucose measurement device. Ten readings for each method were taken simultaneously under the same conditions, and the resulting data were plotted as two separate curves—one for the saliva-based device and the other for the blood glucose measurement device as shown in Fig. 9. and Linear correlation between blood sugar level and glucose concentration of human saliva represented in Fig. 10.

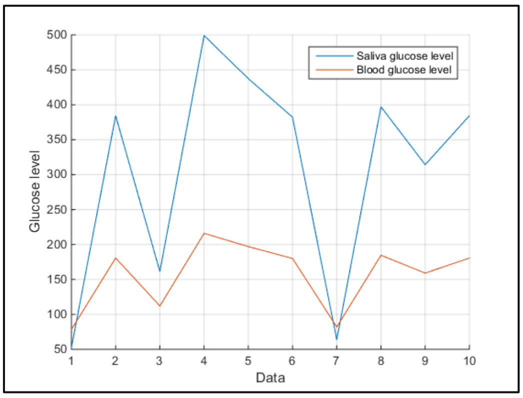

Fig. 9. Comparative between SGL and BGL

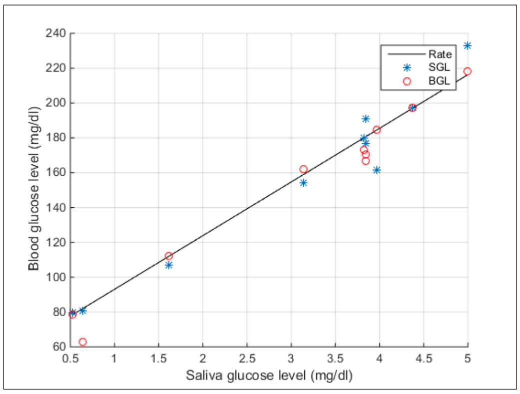

Fig. 10. Linear correlation between blood sugar level and glucose concentration of human saliva.

The simulation results showed that the glucose levels measured using the saliva-based device closely followed the trends observed with the blood glucose measurement device.

While there were minor deviations between the two sets of readings, the overall trend remained consistent, with the saliva-based device demonstrating a good correlation with the blood glucose readings. The differences observed were not significantly large, which indicates that the saliva-based measurement method is promising and capable of providing reliable results for glucose monitoring.

To assess the device's overall performance, this part of the simulation calculates the error margin, accuracy, and sensitivity of the saliva-based glucose monitoring system. To calculate accuracy, measure how close the results of a simulated device are to the true or expected values.The results show a low error margin, which indicates a high degree of accuracy, The following equation shows the relationship between glucose in saliva and blood.The standard curve of BGL and SGL values for different concentrations of glucose can be expressed in the Fig. 10 by the following equation:

$$Y=62.3+30.8X+c \quad (2)$$

Where c is a small variable error rate within a certain range needs improvement to increase the accuracy and sensitivity of the device. Furthermore, the sensitivity analysis confirms that the device responds well to fluctuations in glucose levels, making it a reliable tool for monitoring changes in real time as shown in the Table. 1.

Table 1. Estimated blood glucose construction.

	SGL	BGL
1	0.52509	78.4729
2	3.84363	180.683
3	1.61389	112.008
4	4.99034	216.002
5	4.37451	197.035
6	3.82239	180.029
7	0.63706	81.9216
8	3.97104	184.608
9	3.14286	159.100
10	3.84363	180.683

Although the results are promising, further refinement is needed to enhance the accuracy and reliability of the saliva-based device. The sensitivity of the sensor must be fine-tuned to ensure more precise measurements that closely match the blood glucose levels. Additionally, device calibration will play a crucial role in minimizing the error margins and improving the consistency of the measurements.

Fig. 11. BMEERS simulator app user interface.

6. CONCLUSION

This review highlights the ongoing need to explore non-invasive glucose monitoring, emphasizing the promising potential of alternatives such as saliva, tears, and sweat. With the ability to overcome current limitations, these technologies could revolutionize diabetes management by offering patients accessible, minimally invasive, easy-to-use tools that are lower in cost and less painful. Such advancements could improve compliance, quality of life, and global healthcare outcomes.

The study presented a simulation model of a saliva-based glucose measurement device, which showed strong potential as a non-invasive alternative to traditional blood glucose meters. The device demonstrated good correlation with conventional blood glucose readings, but improvements are needed in sensor calibration and environmental sensitivity to minimize errors related to saliva composition.

Our findings align with previous research on non-invasive glucose measurement, but further optimization is needed for clinical application. The technology could significantly enhance patient comfort, reduce healthcare costs, and simplify continuous glucose monitoring.

In conclusion, while the saliva-based device shows promise, further research is required to refine its accuracy and reliability for widespread use.

7. RECOMMENDATIONS

Based on the results of this study is needed to:

1. Focus on improving the device's performance to ensure greater reliability by improving the biosensor and sensitivity to environmental factors.
2. Determine a package of medical protocols to support the widespread use of the device within health centers.
3. Use artificial intelligence to predict the patient's condition Monitor him and plan a treatment plan.
4. Develop the phone application to include more features such as providing telemedicine services by following up with your private doctor through it, in addition to suggesting the appropriate dietary pattern for each case individually.

REFERENCES

[1] Ong KL, Stafford LK, McLaughlin SA, Boyko EJ, Vollset SE, Smith AE, Dalton BE, Duprey J, Cruz JA, Hagins H, Lindstedt PA. Global, regional, and national burden of diabetes from 1990 to 2021, with projections of prevalence to 2050: a systematic analysis for the Global Burden of Disease Study **2021**. The Lancet. 2023 Jul 15;402(10397):203-34.: https://doi.org/10.1016/s0140-6736(23)01301-6.

[2] "Home Page: Diabetes Research and Clinical Practice," Diabetesresearchclinicalpractice.com, **2019**. https://www.diabetesresearchclinicalpractice.com/

[3] "Diabetes Paper of the Month | American Diabetes Association," Diabetesjournals.org, **2024**. https://diabetesjournals.org/collection/1619/Diabetes-Paper-of-the-Month

[4] The Lancet, "Diabetes: a defining disease of the 21st century," The Lancet, vol. 401, no. 10394, pp. 2087–2087, Jun. **2023**, doi: https://doi.org/10.1016/s0140-6736(23)01296-5.

[5] Cui Y, Zhang H, Zhu J, Liao Z, Wang S, Liu W. Correlations of salivary and blood glucose levels among six saliva collection methods. International Journal of Environmental Research and Public Health. **2022** Mar 30;19(7):4122.: https://doi.org/10.3390/ijerph19074122.

[6] Shettigar L, Sivaraman S, Rao R, Akhila Arun S, Chopra A, U Kamath S, Rana R. Correlational analysis between salivary and blood glucose levels in individuals with and without diabetes mellitus: a cross-sectional study. Acta Odontologica Scandinavica. **2023** Oct 12:1-1.: https://doi.org/10.1080/00016357.2023.2267678.

[7] Jurysta C, Bulur N, Oguzhan B, Satman I, Yilmaz TM, Malaisse WJ, Sener A. Salivary glucose concentration and excretion in normal and diabetic subjects. BioMed Research International. **2009**;2009(1):430426.: https://doi.org/10.1155/2009/430426.

[8] Li N, Zhou Y, Sun H, Wang N, Yang N, Ren P, Fu L, Zhang Y, Liu W, Li Y, Jin J. Rapid analysis of salivary glucose content using MOF/MIPs biomimetic microfluidic paper chips. Chemical Engineering Journal. **2025** Jan 15;504:159023.: https://doi.org/10.1016/j.cej.2024.159023.

[9] Sagana M, Dharman S. Estimation of Salivary and Blood Glucose Level among Patients with Diabetes Mellitus–A Comparative Study. Journal of Pharmaceutical Research International. **2020**;18:20-7., https://doi.org/10.9734/jpri/2020/v32i2030725.

[10] Cinar A, Turksoy K. Factors affecting blood glucose concentration and challenges to AP systems. InAdvances in Artificial Pancreas Systems: Adaptive and Multivariable Predictive Control **2018** Mar 2 (pp. 23-31). Cham: Springer International Publishing.

https://doi.org/10.1007/978-3-319-72245-0_3.
[11] Shirin A, Della Rossa F, Klickstein I, Russell J, Sorrentino F. Optimal regulation of blood glucose level in Type I diabetes using insulin and glucagon. PloS one. **2019** Mar 20;14(3):e0213665. https://doi.org/10.1371/journal.pone.0213665.
[12] Rodríguez-Rodríguez I, Campo-Valera M, Rodríguez JV, Frisa-Rubio A. Constrained IoT-based machine learning for accurate glycemia forecasting in type 1 diabetes patients. Sensors. **2023** Mar 31;23(7):3665 https://doi.org/10.3390/s23073665.
[13] Hassan SM, Riaz RA. Closed loop blood glucose control in diabetics. Biomedical research. **2017** Jul;28(16):7230-6. https://www.researchgate.net/publication/325555138_Closed_loop_blood_glucose_control_in_diabetics
[14] Ionescu C, Zlate S, De Keyser R. An approach to control the blood glucose level in diabetic patients. In2006 IEEE International Conference on Automation, Quality and Testing, Robotics **2006** May 25 (Vol. 1, pp. 48-53). IEEE. https://doi.org/10.1109/aqtr.2006.254495.
[15] Libya, “Noncommunicable diseases,” World Health Organization - Regional Office for the Eastern Mediterranean. https://www.emro.who.int/lby/programmes/noncommunicable-diseases.html
[16] “Libya,” International Diabetes Federation. https://idf.org/our-network/regions-and-members/middle-east-and-north-africa/members/libya/
[17] Lee H, Hong YJ, Baik S, Hyeon T, Kim DH. Enzyme-based glucose sensor: from invasive to wearable device. Advanced healthcare materials. **2018** Apr;7(8):1701150. https://doi.org/10.1002/adhm.201701150.
[18] Yoo EH, Lee SY. Glucose biosensors: an overview of use in clinical practice. Sensors. **2010** May 4;10(5):4558-76., https://doi.org/10.3390/s100504558.
[19] Safarkhani M, Aldhaher A, Heidari G, Zare EN, Warkiani ME, Akhavan O, Huh Y, Rabiee N. Nanomaterial-assisted wearable glucose biosensors for noninvasive real-time monitoring: Pioneering point-of-care and beyond. Nano Materials Science. **2024** Jun 1;6(3):263-83. https://doi.org/10.1016/j.nanoms.2023.11.009.
[20] Zhang B, Wang L, Chang SJ, Jing Y, Sun T, Lei Z, Chen CJ, Liu JT. Flexible cellulose paper-based biosensor from inkjet printing for non-invasive glucose monitoring. Polymer Testing. **2024** Aug 1;137:108527. https://doi.org/10.1016/j.polymertesting.2024.108527.
[21] Jin X, Cai A, Xu T, Zhang X. Artificial intelligence biosensors for continuous glucose monitoring. Interdisciplinary Materials. **2023** Mar;2(2):290-307. https://doi.org/10.1002/idm2.12069.
[22] Chen Z, Wright C, Dincel O, Chi TY, Kameoka J. A low-cost paper glucose sensor with molecularly imprinted polyaniline electrode. Sensors. **2020** Feb 17;20(4):1098.: https://doi.org/10.3390/s20041098.
[23] Peng Z, Xie X, Tan Q, Kang H, Cui J, Zhang X, Li W, Feng G. Blood glucose sensors and recent advances: A review. Journal of Innovative Optical Health Sciences. **2022** Mar 31;15(02):2230003. https://doi.org/10.1142/s1793545822300038.
[24] Gabriel E, Garcia P, Lopes F, Coltro W, “Paper-Based Colorimetric Biosensor for Tear Glucose Measurements,” Micromachines, vol. 8, no. 4, **2017**, p. 104, Mar., https://doi.org/10.3390/mi8040104.
[25] Tang L, Chang SJ, Chen CJ, Liu JT. Non-invasive blood glucose monitoring technology: a review. Sensors. **2020** Dec 4;20(23):6925.: https://doi.org/10.3390/s20236925.
[26] Sharma S, Huang Z, Rogers M, Boutelle M, Cass AE. Evaluation of a minimally invasive glucose biosensor for continuous tissue monitoring. Analytical and bioanalytical chemistry. **2016** Nov;408(29):8427-35.https://doi.org/10.1007/s00216-016-9961-6.
[27] Rodríguez-Rodríguez I, Campo-Valera M, Rodríguez JV, Frisa-Rubio A. Constrained IoT-based machine learning for accurate glycemia forecasting in type 1 diabetes patients. Sensors. **2023** Mar 31;23(7):3665.. https://repositorio.upct.es/entities/publication/b9028978-6214-4c85-9baa-eb88680a6ec0

[28] Shitanda I, Fujimura Y, Nohara S, Hoshi Y, Itagaki M, Tsujimura S. Based disk-type self-powered glucose biosensor based on screen-printed biofuel cell array. Journal of The Electrochemical Society. **2019**;166(12):B1063-8.: https://doi.org/10.1149/2.1501912jes.

[29] Sweeney M. A Review: Biosensor Progression in Glucose Monitoring for Patients with Diabetes. Advances in Bioscience and Biotechnology. 2024 Aug 15;15(8):503-10.: https://doi.org/10.4236/abb.2024.158031.

[30] Panwar S, Sarkar P, Kasim DS, Anand R, Priya A, Prakash S, Jha SK. Portable optical biosensor for point-of-care monitoring of salivary glucose using a paper-based microfluidic strip. Biosensors and Bioelectronics: X. **2024** Apr 1;17:100452.i: https://doi.org/10.1016/j.biosx.2024.100452.

[31] Giaretta J, Zulli R, Prabhakar T, Rath RJ, Naficy S, Spilimbergo S, Weiss PS, Farajikhah S, Dehghani F. Glucose sensing in saliva. Advanced Sensor Research. **2024**4 Nov;3(11):2400065.: https://doi.org/10.1002/adsr.202400065.

[32] Singh AK, Jha SK. Fabrication and validation of a handheld non-invasive, optical biosensor for self-monitoring of glucose using saliva. IEEE Sensors Journal. **2019** May 31;19(18):8332-9.: https://doi.org/10.1109/jsen.2019.2920296.

[33] Santana-Jiménez LA, Márquez-Lucero A, Osuna V, Estrada-Moreno I, Dominguez RB. Naked-eye detection of glucose in saliva with bienzymatic paper-based sensor. Sensors. **2018** Apr 3;18(4):1071.: https://doi.org/10.3390/s18041071.

[34] "US20140197042A1 - Saliva Glucose Monitoring System - Google Patents," Google.com, Jan. 13, **2014**. https://patents.google.com/patent/US20140197042A1/en (accessed Dec. 31, 2024).

[35] Zhang W, Du Y, Wang ML. Noninvasive glucose monitoring using saliva nano-biosensor. Sensing and Bio-Sensing Research. **2015** Jun 1;4:23-9.: https://doi.org/10.1016/j.sbsr.2015.02.002.

[36] Bordbar MM, Hosseini MS, Sheini A, Safaei E, Halabian R, Daryanavard SM, Samadinia H, Bagheri H. Monitoring saliva compositions for non-invasive detection of diabetes using a colorimetric-based multiple sensor. Scientific Reports. **2023** Sep 27;13(1):16174. https://doi.org/10.1038/s41598-023-43262-z.

[37] Omer AE, Shaker G, Safavi-Naeini S, Alquié G, Deshours F, Kokabi H, Shubair RM. Non-invasive real-time monitoring of glucose level using novel microwave biosensor based on triple-pole CSRR. IEEE Transactions on Biomedical Circuits and Systems. **2020** Nov 17;14(6):1407-20.: https://doi.org/10.1109/tbcas.2020.3038589.

[38] "Diabetes," Google Books, **2024**. https://books.google.com.ly/books?id=RVpIAAAAQBAJ&printsec=frontcover&dq=Ref.+1.+Diabetes+An+Old+Disease (accessed Dec. 31, 2024).

[39] Kadashetti V, Baad R, Malik N, Shivakumar KM, Vibhute N, Belgaumi U, Gugawad S, Pramod RC. Glucose level estimation in diabetes mellitus by saliva: a bloodless revolution. Rom J Intern Med. 2015 Jul 1;53(3):248-52. https://doi.org/10.1515/rjim-2015-0032.

[40] Gupta S, Sandhu SV, Bansal H, Sharma D. Comparison of salivary and serum glucose levels in diabetic patients. Journal of diabetes science and technology. **2014** Oct 7;9(1):91-6. https://doi.org/10.1177/1932296814552673.

[41] "Blood Glucose Monitoring: How It Works," Healthline, Jul. 18, 2012. https://www.healthline.com/health/blood-glucose-monitoring#supplies

[42] Tiongco RE, Bituin A, Arceo E, Rivera N, Singian E. Salivary glucose as a non-invasive biomarker of type 2 diabetes mellitus. Journal of clinical and experimental dentistry. **2018** Sep 1;10(9):e902. https://doi.org/10.4317/jced.55009.

[43] Arakawa T, Tomoto K, Nitta H, Toma K, Takeuchi S, Sekita T, Minakuchi S, Mitsubayashi K. A wearable cellulose acetate-coated mouthguard biosensor for in vivo salivary glucose measurement. Analytical Chemistry. **2020** Aug 11;92(18):12201-7. https://doi.org/10.1021/acs.analchem.0c01201.

[44] Arakawa T, Kuroki Y, Nitta H, Chouhan P, Toma K, Sawada SI, Takeuchi S, Sekita T, Akiyoshi K, Minakuchi S, Mitsubayashi K. Mouthguard biosensor with telemetry system for monitoring of saliva glucose: A novel

cavitas sensor. Biosensors and Bioelectronics. **2016** Oct 15;84:106-11. https://doi.org/10.1016/j.bios.2015.12.014.

[45] Sharma A, AlGhamdi WS, Faber H, Lin YH, Liu CH, Hsu EK, Lin WZ, Naphade D, Mandal S, Heeney M, Anthopoulos TD. Non-invasive, ultrasensitive detection of glucose in saliva using metal oxide transistors. Biosensors and Bioelectronics. **2023** Oct 1;237:115448. https://doi.org/10.1016/j.bios.2023.115448.

[46] Lin C, Pratt B, Honikel M, Jenish A, Ramesh B, Alkhan A, La Belle JT. Toward the development of a glucose dehydrogenase-based saliva glucose sensor without the need for sample preparation. Journal of diabetes science and technology. **2018** Jan;12(1):83-9.https://doi.org/10.1177/1932296817712526.

[47] Kumar S, Padmashree S, Jayalekshmi R. Correlation of salivary glucose, blood glucose and oral candidal carriage in the saliva of type 2 diabetics: A case-control study. Contemporary clinical dentistry. **2014** Jul 1;5(3):312-7.https://doi.org/10.4103/0976-237x.137925.

[48] Du Y, Zhang W, Wang ML. An on-chip disposable salivary glucose sensor for diabetes control. Journal of diabetes science and technology. **2016** Nov;10(6):1344-52.https://doi.org/10.1177/1932296816642251.

[49] Du Y, Zhang W, Wang M., "An On-Chip Disposable Salivary Glucose Sensor for Diabetes Control," vol. 10, no. 6, pp. 1344–1352, Jul. **2016**, https://doi.org/10.1177/1932296816642251.

[50] Lin CW, Tsai YH, Peng YS, Yang JT, Lu YP, Chen MY, Tung CW. A Novel Salivary Sensor with Integrated Au Electrodes and Conductivity Meters for Screening of Diabetes. Biosensors. **2023** Jul 2;13(7):702., https://doi.org/10.3390/bios13070702.

[51] Du Y, Zhang W, Wang ML. Sensing of salivary glucose using nano-structured biosensors. Biosensors. **2016** Mar 17;6(1):10., https://doi.org/10.3390/bios6010010.

[52] World Health Organization, "Diabetes," World Health Organization, Nov. 14, **2024**. https://www.who.int/news-room/fact-sheets/detail/diabetes

[53] Goodson JM, Hartman ML, Shi P, Hasturk H, Yaskell T, Vargas J, Song X, Cugini M, Barake R, Alsmadi O, Al-Mutawa S. The salivary microbiome is altered in the presence of a high salivary glucose concentration. PloS one. **2017** Mar 1;12(3):e0170437. https://doi.org/10.1371/journal.pone.0170437.

[54] Puttananjegowda K, Takshi A, Thomas S. An electrospun nanofibrous membrane based electrochemical glucose sensor. IEEE Sensors Letters. **2020** Feb 4;4(2):1-4. https://doi.org/10.1109/lsens.2020.2971515.

[55] Russell S, "Continuous Glucose Monitoring | NIDDK," National Institute of Diabetes and Digestive and Kidney Diseases, Jun. **2023**. https://www.niddk.nih.gov/health-information/diabetes/overview/managing-diabetes/continuous-glucose-monitoring