



Glucose monitoring device by BioSENS digital innovation based on organic thin-film transistors to prevent early diabetes

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ABSTRACT

Background: Diabetes is now one of the most serious chronic diseases in the world, with a growing prevalence globally, including among adolescents. The goal of this research, to develop a non-invasive diagnostic method, is an urgent need. The invasive nature of traditional finger-prick blood glucose tests can discourage patients from regularly monitoring their glucose levels, leading to inadequate disease management and increasing the risk of diabetes complications. **Methods:** The method used is a non-invasive method that measures glucose levels in saliva through a smartphone app. This technology works using Organic Thin-Film Transistors (OTFTs) that integrate glucose oxidase, which reacts with saliva to produce hydrogen peroxide (H₂O₂), which then decomposes into proton ions and electron, triggering an electrical signal. This signal is then processed by a smart device. **Findings:** The BioSENS device enables non-invasive, needle-free blood glucose testing using OTFT-based saliva sensors. Early results show a consistent correlation with blood glucose, highlighting its feasibility. Strengths include painless use, affordability, and ease of use, though clinical validation and regulatory approval are still needed. **Conclusion:** Diabetes in Indonesia requires greater attention. The BioSENS innovation offers a promising non-invasive and accessible approach to support early prevention and monitoring. **Novelty/Originality of this article:** With technological advances, the BioSENS device innovation is present as an effort to prevent diabetes early. BioSENS or Bio-Surveillance and Early Notification System, is a digital innovation based on OTFT with a non-invasive method that can measure glucose levels in saliva through a smartphone application. The BioSENS innovation is expected to receive full support from the government, healthcare workers, and related sectors, to support early detection and prevention of diabetes, thereby improving the nation's health and becoming a step forward in realizing Indonesia's golden generation.

KEYWORDS: health; non-invasive diagnostic; saliva; smartphone app; swot;

1. Introduction

Diabetes mellitus (DM) is a condition in which blood glucose or sugar levels rise above normal limits, preventing the body from producing or using insulin, which can lead to various complications (Ulya et al., 2023). Diabetes is now one of the most serious chronic diseases in the world, with rates continuing to rise globally, including among adolescents. According to a report by the Indonesian Pediatric Society (IDAI, 2023) the prevalence of type 1 diabetes increased 70-fold in children under 18 from 2010 to 2023.

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Lack of monitoring and prevention efforts means many adolescents are unaware that they have diabetes, which ultimately puts them at risk of developing serious complications in adulthood. The International Diabetes Federation (IDF, 2025) reported that 589 million adults (20-79 years old) have diabetes, with more than 40% of them unaware they have the condition. This number is projected to increase to 853 million by 2050. Meanwhile, Indonesia ranks fifth in the world for the number of diabetes sufferers (IDF, 2021). According to data from the Ministry of Health (Kemenkes, 2023), approximately 35 million Indonesians have diabetes. This figure represents approximately 13% of Indonesia's total population of approximately 270 million.

Diabetes has now become a global epidemic, affecting many countries, including Indonesia. Previously considered an adult problem, diabetes is now also affecting adolescents at an alarming rate. According to the Indonesian Health Survey (SKI) (2023) released by the Ministry of Health, the prevalence of diabetes mellitus (DM) among individuals aged 15 years and older rose to 11.7% in 2023, up from 10.9% in 2018 based on blood sugar measurements. This increase signals a rising burden of diabetes, with significant gaps in treatment, especially among productive age groups.

Moreover, the economic impact of diabetes is significant, mainly affecting developing countries in Asia and Africa. According to the International Diabetes Federation (IDF) The estimated global direct health expenditure on diabetes in 2019 is USD 760 billion and is expected to grow to a projected USD 825 billion by 2030. National Health Insurance (JKN) data also shows an increase in the number of diabetes cases and costs in Indonesia, from 135,322 cases with costs of IDR 700.29 billion in 2014 to 322,820 cases with costs of IDR 1.877 trillion in 2017 (Kemenkes, 2018). When patients avoid or reduce the frequency of monitoring, they risk poor glycemic control. This can result in delayed detection of abnormal glucose fluctuations and increase the likelihood of severe complications, including cardiovascular disease, kidney failure, neuropathy, and retinopathy. Therefore, there is a clear clinical and social need for alternative methods that reduce patient burden while maintaining accuracy and reliability (Aggarwal et al., 2022).

Non-invasive diagnostic technologies such as saliva-based biosensors being explored as viable solutions. These approaches eliminate or reduce the need for direct blood sampling, making glucose monitoring more comfortable, accessible, and user-friendly. Beyond convenience, non-invasive systems may also improve patient compliance, leading to better long-term disease management, reduced healthcare costs, and improved quality of life (Boeva et al., 2024). In other word, moving toward non-invasive diagnostics is not only a technological advancement but also a crucial step in addressing the human and behavioral challenges associated with chronic disease monitoring. By prioritizing comfort, accessibility, and accuracy, these innovations have the potential to transform diabetes care and significantly reduce the burden of disease.

Therefore, early detection of DM and pre-DM in adolescents is a crucial first step to improve the health and productivity of the younger generation in the future. In recent years, an increasing number of adolescents have been diagnosed with impaired glucose regulation due to changes in lifestyle, poor dietary habits, and lack of physical activity. Early detection of DM and pre-DM during adolescence is therefore a crucial step that cannot be overlooked. Detecting the condition at an early stage makes it possible to provide timely interventions, such as nutritional guidance, physical activity programs, and lifestyle modifications, which can delay or even prevent the progression to full diabetes (Yachmaneni et al., 2023; An et al., 2024). By identifying adolescents at risk, healthcare providers, educators, and families can work together to create healthier daily routines, prevent long-term complications, and reduce the financial burden of future medical costs. More importantly, early detection ensures that adolescents grow into adults who are not hindered by preventable chronic illnesses. Healthy young people will have greater opportunities to pursue education, careers, and social contributions without being limited by the consequences of unmanaged diabetes (Kaminsky et al., 2022). In short, detecting DM and pre-DM at an early age is not only a medical responsibility but also a societal investment. It safeguards the health,

productivity, and quality of life of the younger generation, preparing them to become healthier and more resilient adults in the future.

Various methods have been developed to monitor glucose concentration in blood. Glucose detection has been the subject of much research in the field of organic electronics, and several varieties of sensors have been reported. Conventional electrochemical techniques, such as cyclic voltammetry and amperometry, have been widely used to determine the concentration of the glucose analyte using the enzyme glucose oxidase (GOX) and these studies have shown promise with very high sensitivities reported. More recently, the studies have focused on developing methods for immobilizing the GOX in a polymer matrix for use as the electrode in electrochemical cells (Elkington et al., 2014). Early work by Macaya et al. (2007) demonstrated that micromolar-level glucose sensitivity could be achieved using organic thin-film transistor (OTFT) device based on the polymer blend, poly(3,4-ethylenedioxythiophene) doped with poly(styrene sulfonate) (PEDOT:PSS), as the semiconducting channel. This work was further expanded by Kanakamedala et al. (2011) who reported that PEDOT:PSS electrochemical devices could be fabricated using a low-cost and rapid xurography technique. However, all of these previous studies required the addition of GOx directly to the glucose analyte, which is impractical for a commercial sensor. This limitation encourages the exploration of strategies for immobilizing GOx directly within the device architecture.

Organic Thin-Film Transistors (OTFTs) have gained attention in the medical and health sector because of their unique properties such as flexibility, biocompatibility, low-cost fabrication, and ability to work on soft substrates. The device configuration of OTFTs meaning how the electrodes, dielectric layers, and organic semiconductors are arranged plays a crucial role in determining how these devices perform in health applications (Liu et al., 2021; Minamiki et al., 2021). Additionally, OTFT configurations are explored in drug delivery systems. Specific designs allow OTFTs to act as microfluidic valves or switches that control the release of drugs in response to biochemical signals. This precise control improves therapeutic efficiency and reduces side effects (Damiati et al., 2018). Overall, the device configuration of OTFTs directly influences their performance in medical applications whether the focus is high sensitivity, mechanical flexibility, or stability in biological environments. By carefully choosing and optimizing the configuration, OTFTs can serve as the foundation for future non-invasive diagnostic devices, wearable monitors, neural interfaces, and smart therapeutic systems.

The purpose this study is to develop and evaluate an OTFT-based biosensor for the non-invasive measurement of glucose concentration in human saliva. This study aims to explore the feasibility of using OTFT technology as a low-cost, flexible, and highly sensitive platform for biochemical sensing. Specifically, the objectives include designing and fabricating an OTFT sensor integrated with a glucose oxidase enzyme layer as a bio-recognition element, investigating the sensor's performance, including its sensitivity, selectivity, linearity, stability, and response time, in detecting glucose concentrations typically found in saliva (0.008–0.2 mM) and demonstrating the practical application of the OTFT biosensor as a non-invasive, portable, and user-friendly device for continuous glucose monitoring.

2. Methods

This work presents the development of a simple OTFT design featuring poly(3-hexylthiophene) (P3HT) as the semiconducting layer, and a gate electrode consisting of a film of Nafion (a polymeric membrane material) loaded with a sensing enzyme. This electrode forms the recognition elements of the OTFT-based sensor and exhibits sensitivities to glucose in the sub-millimolar concentration range. The work presented here demonstrates a practical self-contained architecture for a printable OTFT-based glucose sensor that is sensitive in the range of concentrations for glucose in saliva, where the enzyme is embedded into the device itself.

The device configuration of the Organic Thin-Film Transistor (OTFT) used in this study is illustrated in Fig. 1, which presents two different design approaches for glucose sensing applications. Figure 1(a) shows the BioSENS device architecture, while Fig. 1(b) depicts the conceptual configuration of a sensor integrated with the glucose oxidase (GOX) enzyme for detecting glucose presence. These configurations highlight the arrangement of key functional layers, including the substrate, electrodes, semiconductor, and sensing components, which collectively determine the device performance. The integration of GOX within the sensing layer plays a crucial role in enabling the biochemical-to-electrical signal transduction mechanism required for non-invasive glucose detection.

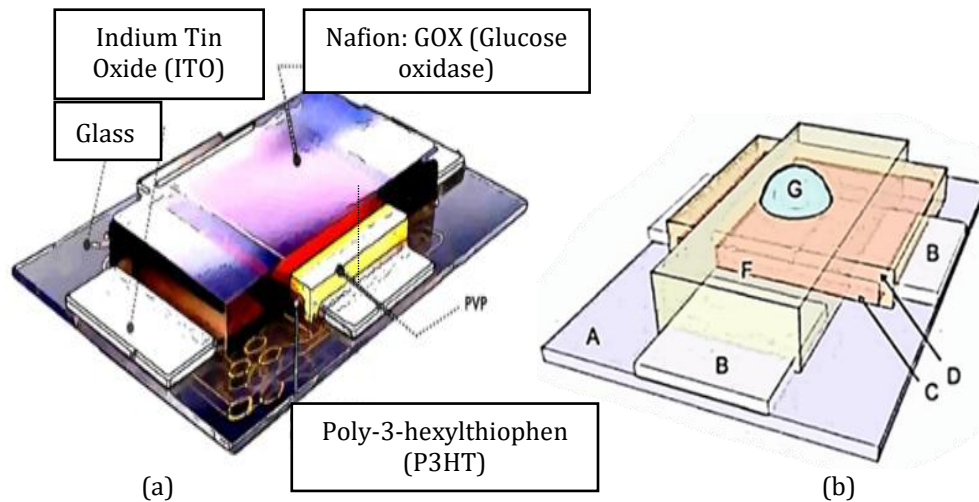


Fig. 1. Device configuration of two types of OTFTs (a) BioSENS device; (b) Illustration of a sensor device equipped with the enzyme GOX to detect the presence of glucose

2.1 Tools and materials

Glass serves as a substrate on which all sensor layers are built, ensuring proper attachment of all components (see Fig. 1). In OTFTs glass serves as the substrate, which is essentially the foundation or base layer of the device. Its main functions are as mechanical support where glass provides a stable and rigid platform where all other layers of the OTFT—such as the semiconductor, dielectric, electrodes, and sensing materials—can be deposited (Meza-Arroyo et al., 2025). It ensures that these thin layers remain intact and properly aligned without bending or warping. A flat base reduces defects in the active layers, which improves electrical performance and sensitivity of the OTFT. This ensures that the electrical signals measured in the OTFT come only from the intended sensor layers. In optoelectronic or biosensing applications, transparent glass substrates allow light to pass through, enabling optical detection or integration with optical systems. Glass in OTFTs acts as the solid base that supports, insulates, and protects the functional sensor layers, while also providing a smooth and stable surface for high-performance device operation.

ITO acts as the source and drain electrodes for electrical current. Because ITO is conductive and transparent, it helps control the electric current in the transistor. In OTFTs, ITO plays an important role, most commonly serving as the transparent electrode material (Fig. 2). It combines high electrical conductivity with optical transparency (Naghdi et al., 2018). This means it can carry electrical charges effectively while still allowing light to pass through, a feature that is critical in optoelectronic devices such as displays, sensors, and organic transistors. Because OTFTs are usually fabricated on transparent substrates such as glass or flexible plastic, ITO ensures that the overall device maintains optical clarity, making it suitable for applications like flexible displays biosensors. Its surface also provides a stable and uniform platform for the deposition of organic semiconductor layers.

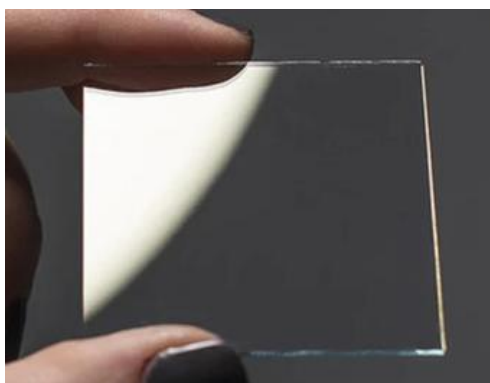


Fig. 2. Transparent substrates ITO to ensure that the overall device maintains optical clarity

Acts as a semiconductor layer through which electrons move, carrying current. In the experimental method of OTFTs, P3HT is often employed as the semiconducting active layer due to its high charge carrier mobility, solubility in organic solvents, and ability to form well-ordered thin films. In the testing stage, the fabricated OTFT devices are electrically characterized by measuring the current-voltage (I-V) characteristics under controlled environmental conditions. The focus is on parameters such as field-effect mobility, threshold voltage, on/off current ratio, and subthreshold slope, which provide insights into the semiconducting properties of P3HT. The performance is highly dependent on how the polymer chains pack and align within the thin film, making the processing conditions critical (Melville et al., 2015).

An insulator or dielectric layer, PVP acts as a regulator of charge flow to ensure a stable flow and a separator between the electrode and the semiconductor layer, allowing the device to respond only to changes in the detected glucose, without interference from other charges in the surrounding environment. The PVP was employed as the gate dielectric layer in the fabrication of OTFTs. PVP powder was first dissolved in propylene glycol monomethyl ether acetate (PGMEA) at an appropriate concentration, typically in the range of 5–10 wt%. To improve the dielectric stability and reduce leakage current, poly(melamine-co-formaldehyde) (PMF) was added as a crosslinking agent at a ratio of approximately 1:10 with respect to PVP. The solution was stirred overnight at room temperature until complete dissolution was achieved (Wang et al., 2022).

The prepared PVP solution was filtered through a 0.45 μm PTFE filter before deposition. The film was deposited onto the cleaned ITO/glass substrate by spin-coating at 3000 rpm for 30–60 seconds to obtain a uniform thin layer. The coated substrates were subsequently soft-baked on a hot plate at 80–100 $^{\circ}\text{C}$ to remove residual solvent, followed by a curing step at 200 $^{\circ}\text{C}$ for 1 hour to initiate crosslinking of the PVP/PMF matrix. This thermal treatment ensured the formation of a smooth, stable, and insulating dielectric layer with low surface roughness. After the dielectric layer preparation, the organic semiconductor was deposited on top of the cured PVP layer, completing the transistor channel structure. The use of PVP as a dielectric provided good insulating properties, surface planarity, and compatibility with organic semiconductors, which are critical for the performance of OTFT devices (Sun et al., 2025).

The conductive polymer for the electrode was replaced by Nafion, which contains the enzyme GOX, to enable the electrode to detect glucose. Acts as a conductive gate electrode or as a hole injection layer between the electrode (ITO or metal) and the organic semiconductor. It provides smooth, uniform, and flexible conductive surfaces that improve charge transport. In other word, the experimental method with PEDOT:PSS in OTFTs involves preparing and coating PEDOT:PSS onto the substrate, annealing for conductivity, layering organic semiconductors and dielectrics, and then testing the transistor's performance (Nabajyoti et al., 2023).

The nafion layer contains the enzyme glucose oxidase (GOX), which reacts with glucose to produce hydrogen peroxide (H_2O_2). Protons from the H_2O_2 change the transistor's

electrical properties, allowing it to recognize and respond to the presence of glucose. As an operation of the sensor, during testing, a sample of saliva (or glucose solution) is introduced. Glucose in the sample reacts with GOX inside the Nafion layer, producing H_2O_2 and protons (H^+). These protons modify the local charge distribution, which shifts the electrical characteristics of the OTFT channel (e.g., drain current, threshold voltage).

As a signal measurement, the change in current is recorded using an electrical measurement system (such as a semiconductor parameter analyzer). The output current is correlated with glucose concentration, forming the basis of the sensing mechanism (Lorencova et al., 2024).

The substance detected is a droplet of glucose-containing solution. Glucose in saliva is considered a key analyte for non-invasive glucose monitoring because it reflects blood glucose levels without requiring painful finger-prick tests. When saliva containing glucose comes into contact with the sensing layer of the OTFT device, which is usually functionalized with enzymes such as GOX, a biochemical reaction occurs. The enzyme catalyzes the oxidation of glucose, producing H_2O_2 and releasing protons and electrons. These reaction products change the local electrical environment around the OTFT channel. As a result, the transistor's electrical characteristics, such as current flow or threshold voltage, are modified in response to the presence and concentration of glucose. This signal modulation is then measured and correlated with the glucose concentration in the saliva sample. Because OTFTs can be integrated with flexible and miniaturized platforms, this makes them suitable for wearable or portable diagnostic devices (Giaretta et al., 2024).

BioSENS or Bio-Surveillance and Early Notification System, is a digital innovation based on OTFTs with a non-invasive method that can measure glucose levels in saliva via a smartphone app. This technology works by using OTFTs that integrate glucose oxidase, which reacts with saliva to produce H_2O_2 , which then decomposes into proton ions and electron, triggering the formation of an electrical signal. This signal is then processed by a smart device (see Fig. 3).

Digital innovation in healthcare is rapidly advancing toward non-invasive, user-friendly, and highly sensitive diagnostic tools. One promising development is the integration of OTFTs as biosensing platforms for glucose monitoring in saliva, connected to smartphone applications. Unlike conventional invasive methods such as finger-prick blood tests, this approach offers a painless and continuous monitoring system, which can greatly improve patient compliance and quality of life, especially for individuals with diabetes or pre-diabetes (Lukito et al., 2024).

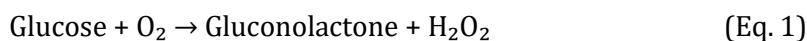
The operational principle of this technology relies on the unique properties of OTFTs combined with biochemical sensing elements. OTFTs are organic semiconducting devices capable of translating biochemical reactions into measurable electrical signals due to their high sensitivity to surface charge and molecular interactions. In this application, the OTFT is functionalized with GOx, an enzyme that specifically reacts with glucose molecules present in saliva. When glucose in the saliva comes into contact with glucose oxidase, a catalytic reaction occurs, producing H_2O_2 as a byproduct.

The hydrogen peroxide generated in this enzymatic reaction undergoes further decomposition, releasing protons (H^+) and electrons (e^-). These charged species induce changes in the local electrochemical environment at the OTFT surface. Because OTFTs are highly responsive to variations in ionic and electronic charge, the presence of protons and electrons alters the transistor's electrical conductivity and modulates its channel current. This change in current effectively becomes a quantifiable electrical signal that directly corresponds to the concentration of glucose in saliva (Ucar et al., 2025).

The next stage involves digital integration. The electrical signal output from the OTFT biosensor is transmitted to a processing unit that can be embedded within a portable or wearable device. Through wireless connectivity, the data is then synchronized with a smartphone application. The app processes the raw electrical signals, applies calibration algorithms, and converts them into readable glucose level values displayed to the user in real time. This digital ecosystem not only enables continuous, non-invasive glucose

monitoring but also provides advanced features such as long-term data storage, trend analysis, and integration with healthcare platforms for remote patient monitoring.

In summary, OTFT-based glucose monitoring systems represent a transformative innovation in biomedical engineering. By combining organic electronic materials, enzymatic bio-recognition, and digital mobile technologies, these devices enable the non-invasive detection of glucose levels in saliva with high specificity and sensitivity. The seamless integration with smartphone applications further enhances accessibility, making this technology a powerful tool for diabetes management and preventive health strategies in the digital era. When saliva containing glucose touches the Nafion-GOX layer, a reaction occurs that produces H_2O_2 and releases protons. In this step, a highly specific biochemical reaction takes place. Nafion is a polymer that serves as a matrix or support material, while GOX is an enzyme that plays the key role in detecting glucose molecules. Glucose oxidase has the natural ability to recognize glucose as its substrate and catalyze its oxidation. As glucose diffuses from saliva into the Nafion layer, it encounters the embedded glucose oxidase enzyme. The enzyme initiates a redox reaction in which glucose is oxidized to gluconolactone, while molecular oxygen is simultaneously reduced. This reduction of oxygen leads to the generation of H_2O_2 as a byproduct. The process can be represented by the simplified reaction Equation 1. The produced hydrogen peroxide does not remain inert. Instead, it undergoes decomposition into water and reactive oxygen species, which release free protons (H^+) (Bauer et al., 2022).



These protons, along with the electrons generated from the reaction, significantly alter the local electrochemical environment of the Nafion film. Since Nafion is known for its proton-conducting properties, the presence of these newly released protons enhances its ionic conductivity. This shift in proton concentration and charge distribution is crucial because it can be transduced into an electrical signal when coupled with an electronic sensing platform, such as an OTFT. In this way, the initial biochemical reaction that begins with glucose in saliva is translated into a measurable electrical output, forming the basis for non-invasive glucose monitoring technologies. These protons then affect a conductive material called P3HT, changing its conductivity to conduct electricity. This change is then detected by the ITO electrode, which converts it into an electrical signal.



Fig. 3. The BioSENS device sends a signal to the app

3. Results and Discussion

The OTFTs are flexible electronic devices that can detect biological molecules like glucose in saliva through changes in electrical signals. The process works as follows the sample collection with a small amount of saliva is collected from the mouth using a swab or

directly placed onto the sensor surface of the OTFT device. Saliva naturally contains glucose, although at much lower concentrations than blood. By sensing layer reaction the OTFT sensor has a bio-recognition layer (coated with an enzyme *glucose oxidase*). When the glucose in saliva comes into contact with this layer, a biochemical reaction occurs produces H_2O_2 and changes the local charge or current near the transistor surface. The electrical signal detection detects these changes because the reaction products modify the electrical properties (like current, voltage, or conductivity) of the transistor's channel. The degree of change is proportional to the glucose concentration in the saliva. Signal is processed and converted into a quantitative glucose value, typically displayed on a connected reader or smartphone app (Fig. 4).

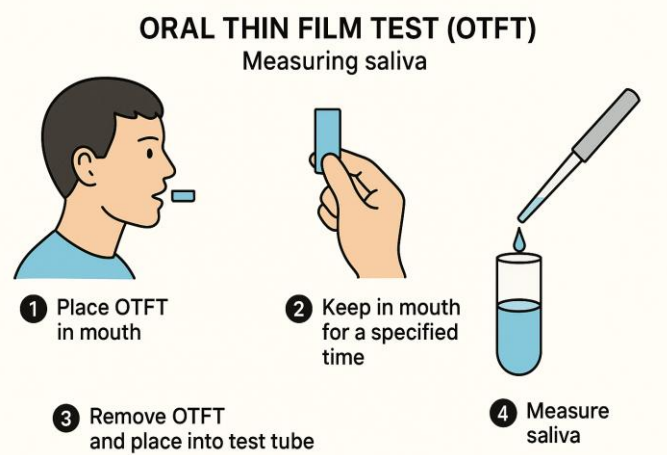


Fig. 4. The procedure of saliva testing by using OTFTs principal

As the result interpretation an estimate of the salivary glucose level, which can correlate with blood glucose levels, offering a non-invasive alternative to traditional blood-based glucose testing. From this signal, the system can detect glucose levels in saliva, which are then displayed via an application. The application not only provides glucose levels, but also offers various other features, such as an "Education" feature about diabetes and a "Statistics" feature for daily glucose measurements. Through this breakthrough, BioSENS is expected to optimize diabetes prevention efforts to be more effective and sustainable (see Fig 5).

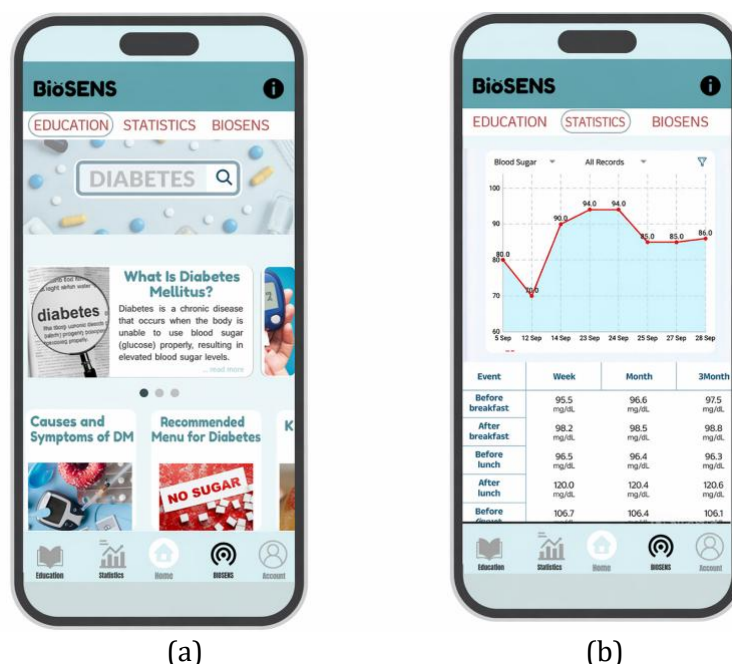


Fig. 5. (a) Education feature (provides information about DM); (b) Statistics feature (records the results of each measurement)

This study presents a conceptual design and theoretical feasibility analysis of an OTFT-based salivary glucose monitoring system. The proposed architecture is based on previously reported OTFT biosensing principles and literature supported performance parameters. By current research status, the OTFT glucose sensors have excellent potential for non-invasive, wearable biosensing. It is valid in laboratory prototypes and proof of concept studies (Table 1). However not yet clinically validated or approved for medical use, for instance, FDA or CE mark. Meanwhile the research is ongoing to improve stability, reproducibility, and calibration algorithms.

The use of OTFT sensors for glucose detection in saliva represents an innovative, non-invasive diagnostic approach that is still in the experimental stage. From a scientific standpoint, the concept is strong and well-founded. It relies on established biochemical principles—specifically, the enzymatic reaction between glucose oxidase and glucose that produces hydrogen peroxide, which in turn modulates the electrical current on the transistor surface. This mechanism provides a measurable electronic signal corresponding to glucose concentration. In terms of analytical performance, current studies show promising sensitivity and selectivity (see Table 1). However, results remain variable due to factors such as enzyme stability, salivary matrix interference, and environmental conditions that may affect measurement consistency. These issues indicate that while the sensor's analytical foundation is sound, further refinement is necessary to ensure reproducible and reliable outcomes across diverse samples.

Table 1. Validation of several aspects from OTFT glucose sensors

Aspect	Current Validity
Scientific basis	Strong
Analytical performance	Promising but variable
Clinical correlation	Moderate
Regulatory acceptance	Not yet approved
Overall	Experimentally valid, not yet clinically validated

Regarding clinical correlation, existing research demonstrates a moderate relationship between glucose levels in saliva and those in blood. Although there is a measurable correlation, the variability in salivary composition among individuals makes precise clinical interpretation challenging. Hence, more extensive clinical trials are required to establish robust calibration models linking salivary glucose to blood glucose. From a regulatory perspective, OTFT-based saliva glucose sensors have not yet gained formal approval for clinical use. They remain within the realm of laboratory research and prototype testing, pending standardized validation protocols and long-term performance evaluations. Overall, OTFT glucose sensors can be considered experimentally valid but not yet clinically validated. They hold significant potential for non-invasive glucose monitoring in the future, but require further optimization, clinical validation, and regulatory review before being adopted as reliable diagnostic tools. In the context of OTFT-based glucose sensors using saliva as the testing medium, several key performance factors determine the accuracy and reliability of the measurement.

Sensitivity refers to the sensor's ability to detect glucose at the very low concentrations typically present in saliva, which range between 0.008 and 0.2 mM, much lower than the glucose concentration found in blood (3–8 mM). Some OTFT sensors have demonstrated the capability to detect glucose within this range, but achieving such sensitivity requires the development of high-quality enzyme layers and stable interfacial structures that can effectively transduce the biochemical reaction into an electrical signal.

Specificity is another crucial factor, as the sensor must accurately distinguish glucose from other chemically similar molecules that are also present in saliva, such as lactose, uric acid, and ascorbic acid. This challenge can be addressed by employing selective surface coatings and advanced modification techniques, such as incorporating Nafion layers, which act as selective barriers to prevent interference from non-glucose substances, thereby enhancing the precision of glucose detection.

Lastly, reproducibility concerns the ability of the sensor to provide consistent and reliable results over multiple tests. This aspect remains one of the most significant challenges in saliva-based OTFT glucose sensing, primarily due to factors like biofouling (the accumulation of biological materials on the sensor surface), enzyme degradation over time, and the natural variability of saliva composition among different individuals and even within the same person under varying conditions.

Overall, while OTFT glucose sensors show strong potential for non-invasive glucose monitoring through saliva, achieving high sensitivity, specificity, and reproducibility simultaneously remains an ongoing area of research and technological refinement (see Table 2).

Table 2. The ability factors of OTFT sensors relating to achievements and current developments

Factor	Description	Current Status
Sensitivity	Can detect glucose at low levels typical in saliva (0.008–0.2 mM, much lower than blood 3–8 mM).	Some OTFT sensors achieve this, but require high-quality enzyme layers and stable interfaces.
Specificity	Must distinguish glucose from other similar molecules (lactose, uric acid, ascorbic acid, etc.).	Selective coatings and surface modification (e.g., Nafion layers) can improve specificity.
Reproducibility	Consistent results over repeated tests.	Still a challenge due to biofouling, enzyme degradation, and variable saliva composition.

3.1 The urgency and solution for preventing diabetes in Indonesia

Indonesia is facing a rising trend of diabetes, creating an urgent need for sustainable prevention strategies. Sugary food consumption carries a variety of serious health risks. The Indonesian Ministry of Health notes that uncontrolled type 1 diabetes can lead to various health problems, such as nerve damage, impaired vision, kidney failure, and the risk of heart disease. If left untreated, type 1 diabetes can be life-threatening and even fatal.

The significant increase in the number of diabetes sufferers in Indonesia deserves serious attention from the government. However, the relatively high cost of diabetes treatment and testing, along with the invasive methods using needles, are widely feared. This can be a particular challenge for patients who require regular blood sugar monitoring, such as those with type 1 diabetes, who may need to test their blood glucose levels several times a day. The need for frequent blood sampling can also lead to infections, especially if patients do not follow proper hygiene protocols (American Diabetes Association, as cited in Ko & Liao, 2023). Therefore, the development of non-invasive diagnostic methods is an urgent need, because the invasive nature of traditional blood glucose tests with blood sampling through finger pricks can discourage patients from monitoring their glucose levels regularly, leading to inadequate disease management and increasing the risk of diabetes complications.

3.2 Potentials that can be utilized and SWOT analysis

Recently technological developments have penetrated the healthcare sector, facilitating access to more practical and affordable healthcare. Therefore, saliva analysis offers a convenient, non-invasive alternative that can be used anywhere and anytime. Many researchers have demonstrated a correlation between saliva detection and increased blood glucose levels, leading to the development of diabetes. Saliva is a fluid containing various substances, such as hormones, enzymes, antibodies, and several other growth factors, similar to blood. These substances are expressed in saliva from the blood, passing through the intercellular space through active and passive methods. Therefore, many blood components are found in saliva, making it highly potential for early detection of systemic diseases such as diabetes (Hu et al., 2025). The strengths and weaknesses of BioSENS were identified through a SWOT analysis as follows Table 3.

Table 3. SWOT analysis

Strengths	<ul style="list-style-type: none"> a. Convenient and practical: BioSENS is designed with a non-invasive method that utilizes saliva as a detection medium without blood draws, making it much more practical and painless. b. Efficient Recovery and Examination Time: With an OTFT-based detection system, BioSENS enables fast and efficient glucose level monitoring, accelerating early diagnosis without requiring recovery time because it does not cause scars. c. Wide accessibility: This device is designed for independent use at home using only a smartphone. Therefore, BioSENS is highly suitable for the wider community, including those in areas with limited access to healthcare facilities. d. Cost-effectiveness: Prevention and treatment of diabetes mellitus are often expensive. BioSENS offers a more economical health monitoring solution because it does not require consumables such as needles or test strips, and reduces reliance on hospital care.
Weaknesses	<ul style="list-style-type: none"> a. Contamination risk for medical personnel: The safety of medical practitioners handling samples can be compromised by bacterial or viral infections from saliva. b. Requires a digital device such as a smartphone and an internet connection, requiring network and battery power to obtain test results.
Opportunities	<ul style="list-style-type: none"> a. High number of diabetes sufferers: The incidence of diabetes is increasing annually and is predicted to become more severe, thus increasing the need for innovations in diabetes prevention. b. Technological advancements: With increasingly advanced developments and advances in technology, there are significant opportunities for BioSENS to develop as a modern solution aligned with the trend of digitalization of healthcare services. c. Support from government and healthcare institutions: Support for health innovations from agencies such as the Ministry of Health and healthcare digitalization programs.
Threats	<ul style="list-style-type: none"> a. Competition from similar technologies: The emergence of advanced technology in the form of non-invasive glucose monitoring devices from global companies could become strong competitors. b. Public perception that is not yet fully convinced and trusting of the accuracy of new innovations.

3.3 Strategic steps and parties involved in implementing BioSENS

The implementation of BioSENS involves several systematic steps. First, collaboration with health institutions such as community health centers (Puskesmas) or hospitals is essential to ensure that the device meets medical and bioethical standards in terms of accuracy, safety, and effectiveness in real-world applications. This collaboration also supports the broader implementation of the device, particularly among adolescents. Second, the socialization of device use plays a crucial role in increasing public awareness of the importance of early glucose monitoring. For instance, schools can serve as strategic platforms for introducing BioSENS to students, which may further support the development of preventive policies against diabetes from an early age. Finally, the evaluation and development phase is conducted after the implementation of BioSENS. This stage involves periodic assessments of the device's effectiveness as a preventive tool for early detection of diabetes risk. The evaluation is carried out by observing behavioral changes and the impact of BioSENS usage on users' lifestyle patterns. The findings from this process are then utilized for continuous improvement and refinement, enabling BioSENS to offer glucose monitoring solutions that are increasingly aligned with the needs of the community in the future.

The implementation of BioSENS has potential societal impacts, particularly in improving public awareness of early diabetes detection. By providing a simple and non-invasive monitoring device, individuals could be more motivated to regularly check their

glucose levels. This could encourage preventive behavior, including healthier lifestyle choices and early medical consultation. In developing countries such as Indonesia, where access to healthcare services may be limited, portable and affordable technologies like BioSENS can bridge the gap between patients and healthcare providers. Consequently, this innovation may contribute to reducing the long-term burden of diabetes and improving overall population health outcomes.

The successful implementation of BioSENS requires collaboration among multiple stakeholders. First, the public, particularly health-conscious adolescents, serves as the primary target group. These individuals are expected to use BioSENS to independently monitor their blood glucose levels, enabling early detection of diabetes symptoms or fluctuations in blood sugar levels. Second, health support workers, including doctors, nurses, and other medical personnel, play a vital role in ensuring the effectiveness of BioSENS. Their involvement is essential in bridging health-related knowledge to patients, providing accurate diagnoses, and determining appropriate medical interventions when necessary. Third, academics contribute through research and evaluation activities. They are responsible for assessing the performance of BioSENS and conducting studies that support continuous monitoring and improvement of the device. Fourth, the Ministry of Health (Kemenkes) plays a strategic role in supporting the integration of BioSENS into national health programs, such as those implemented in community health centers (Puskesmas) and schools. Additionally, the ministry is responsible for overseeing the safety and effectiveness of the device to ensure compliance with established medical standards. Fifth, the technology and telecommunications sector is crucial in developing and maintaining the digital platform of BioSENS. This sector also provides the necessary digital infrastructure and network services to ensure the system operates effectively across various regions, including remote areas. Finally, the government supports the implementation of BioSENS by providing facilities as well as conducting monitoring and evaluation processes to enhance the overall performance and sustainability of the program. This cross-sector collaboration is crucial to ensure that BioSENS is not only a sophisticated medical technology, but also operationally effective and has a real impact on improving national health.

4. Conclusions

Based on the above discussion, it can be concluded that diabetes in Indonesia requires attention, especially among young people. Several screening efforts have been carried out, yet the relatively high cost of treatment and DM testing, along with the invasive method using syringes, are widely feared and carry the risk of infection, especially if patients do not follow proper hygiene protocols. Therefore, by leveraging current technological advances, the BioSENS device innovation is present as an effort to prevent diabetes early. BioSENS or Bio-Surveillance and Early Notification System, is a digital innovation based on OTFT with a non-invasive method that can measure glucose levels in saliva through a smartphone application. The main advantages of this innovation are its non-invasive nature, ease, affordability, and painlessness because it does not require the use of needles or lancets, making it a convenient option. The success of this initiative relies on the involvement of various parties, especially healthcare workers who have officially partnered. However, this study remains conceptual in nature, and further work is required, including prototype development, experimental testing, and clinical validation to confirm the feasibility and reliability of the proposed system in real-world applications.

By SWOT analysis of OTFT-based saliva glucose sensors that this emerging technology possesses significant potential as a non-invasive, flexible, and low-cost alternative to conventional blood glucose testing. The strengths lie in its high sensitivity to low glucose concentrations, compatibility with flexible substrates, and ability to integrate into wearable or disposable biosensing platforms. However, weaknesses such as limited long-term stability, variability in saliva composition, and challenges in enzyme immobilization remain critical technical barriers. On the opportunity side, advancements in organic semiconductor materials, surface functionalization, and microfabrication offer pathways to improve sensor

reliability and reproducibility. Growing global demand for painless, continuous glucose monitoring further enhances its market potential. Nonetheless, threats include competition from established electrochemical and optical glucose sensors, lack of regulatory approval, and potential biocompatibility issues in real-world applications.

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Author Contribution

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During the preparation of this work, the author(s) used ChatGPT (OpenAI) to assist in improving language clarity, grammar, and academic writing style. After using this tool, the author(s) reviewed, revised, and ensured the accuracy and integrity of the content and take full responsibility for the final version of the manuscript.

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