# THE USE OF WEARABLE DEVICES FOR BLOOD GLUCOSE MONITORING IN DIABETES MELLITUS PATIENTS: A COMPREHENSIVE REVIEW OF TECHNOLOGY, CLINICAL IMPACT, AND FUTURE PROSPECTS

**Muh Zukri Malik[1], Nirmala Amir[2]**
[1]*STIKES Panakkukang (Indonesia)*
[2]*RSPTN Universitas Hasanuddin (Indonesia)*

**Corresponding author: zukrimalik@gmail.com*

## Abstract

Accurate and continuous blood glucose (glucose) monitoring is a crucial cornerstone of effective diabetes management. Wearable devices have emerged as transformative technology, promising significant improvements in glucose monitoring compared to conventional (fingerstick) methods. This comprehensive review explores the landscape of wearable technology for glucose monitoring, analyzes its clinical impact, and outlines future prospects. We conducted a systematic literature search on leading scientific databases (PubMed, IEEE Xplore, Scopus) for recent studies (2019-2025). This review categorizes key technologies, including electrochemical enzymatic sensor-based Continuous Glucose Monitoring (CGM), optical sensors (NIR/MIR spectroscopy, Raman, fluorescence), and multimodal approaches integrated into patches, smartwatches, or textile-based devices. Analysis of the clinical impact shows strong evidence that the use of wearable CGM improves glycemic control (statistically significant HbA1c reduction), reduces hypoglycemia incidents, increases patient adherence, and enhances diabetes-related quality of life. However, challenges such as accuracy under extreme physiological conditions, calibration, sensor lifespan, cost, and patient data interpretation still persist. Promising future prospects include the development of truly non-invasive sensors, enhanced integration with Artificial Intelligence (AI) algorithms for prediction and personalized recommendations, expanded applications for prediabetes and non-diabetic populations, and advancements in miniaturization and biocompatibility. It is concluded that wearable devices for glucose monitoring are revolutionizing diabetes management, offering substantial clinical benefits. Continued research and multidisciplinary collaboration are essential to overcome remaining challenges and realize the full potential of this technology in improving global population health.

Keywords: Wearable, Technology, Blood Glucose, Diabetes Mellitus.

## 1. INTRODUCTION

Diabetes Mellitus (DM) represents a significant global health challenge, with its prevalence continuously and significantly increasing (Saeedi et al., 2019). Accurate and continuous blood glucose monitoring is a critical pillar of optimal diabetes management, enabling timely adjustments to therapy (diet, exercise, medication) to achieve glycemic targets and prevent both acute complications (hypo/hyperglycemia) and chronic ones (International Diabetes Federation, 2021). Conventional methods of self-monitoring of blood glucose (SMBG) via fingerstick have several key limitations. These include their invasive nature, causing discomfort and pain; providing intermittent "snapshot" data that can miss important glycemic fluctuations; and often leading to suboptimal patient adherence (Foster et al., 2019). These limitations have spurred the search for more advanced glucose monitoring technologies. Wearable devices—electronic devices that can be worn on the body—have emerged as a highly promising solution over the last decade. This technology offers the potential for continuous, less invasive or even non-invasive, and convenient glucose monitoring, thereby potentially revolutionizing daily diabetes management practices (Bandodkar et al., 2020).

This comprehensive review aims to: Present an in-depth overview of available and emerging wearable technologies for glucose monitoring. Evaluate the clinical impact of implementing these technologies based on current evidence.

Discuss existing challenges and exciting future prospects in this rapidly evolving field..

## 2. METHODOLOGY

This systematic literature review was conducted following recommended principles for comprehensive narrative reviews.

**Data Sources**

An extensive literature search was performed across major electronic scientific databases, including PubMed/MEDLINE, IEEE Xplore, Scopus, and Web of Science Core Collection.

**Search Strategy**

Both controlled vocabulary terms (MeSH, Emtree) and free-text keywords were used in combination, covering core concepts such as:

("wearable device" OR "wearable sensor" OR "continuous glucose monitor" OR CGM OR "non-invasive glucose monitoring") AND

("blood glucose" OR glycemia OR diabetes) AND

(technology OR accuracy OR "clinical outcome" OR impact OR future)

A temporal filter was applied to prioritize recent publications (2019-2025), although relevant foundational papers published prior to this period were also included.

**Selection Criteria**

Included studies comprised:

Systematic reviews and meta-analyses.

Randomized Controlled Trials (RCTs).

Prospective cohort studies.

In-vitro and in-vivo (animal/human) technical validation studies.

Conceptual papers/technical reports describing relevant novel wearable technologies.

Opinion pieces, single case reports, and studies with weak methodologies were excluded.

**Data Analysis**

Extracted data included:

Type of wearable technology.

Detection principle.

Accuracy (Mean Absolute Relative Difference - MARD).

Key clinical outcomes (HbA1c, hypoglycemia incidence, adherence, quality of life).

Advantages.

Limitations.

Future trends.

Synthesis was conducted narratively, grouping findings by major themes (technology, clinical impact, prospects).

## 3. RESULTS

The review results of the obtained articles explain that the development of technological devices for monitoring blood sugar levels in diabetes mellitus patients is a realizable hope. The presence of such technology can have a positive clinical impact that helps maintain patients' quality of life. The article search conducted using specific keywords yielded 128,635 articles, but the subsequent selection process resulted in approximately 13 research articles ready for review.

### 3.1 Wearable Technology:

#### 3.1.1 Electrochemical Continuous Glucose Monitoring (CGM)

These systems use enzymatic sensors (typically glucose oxidase or dehydrogenase) that are inserted subcutaneously. They measure an electrochemical signal proportional to interstitial glucose concentration (Vashist, 2020). Examples include Dexcom G7 and Abbott Free Style Libre 3. They achieve high accuracy (MARD ~7-9%) and have a lifespan of up to 14 days. However, they still require calibration (with the exception of some models) and are minimally invasive.

#### 3.1.2 Optical Sensors

Spectroscopy: This category includes Near-Infrared (NIR), Mid-Infrared (MIR), and Raman spectroscopy, which measure light absorption or reflection by glucose (Tura et al., 2021). Challenges include interference from other blood components, skin effects, and the need for powerful light sources and detectors.

Fluorescence: These methods utilize fluorescent sensors that respond to glucose (Zhang et al., 2024). They typically require implantable or dermal sensors.

Polarimetry: This technique measures the rotation of the plane of polarized light by glucose (Smith, 2022). It is highly sensitive to motio.

#### 3.2.5 **Platform Wearable**

These sensors are integrated into various wearable formats, such as disposable patches, smartwatches, rings, or smart textiles (e-textiles).

### 3.2 Clinical Impact::

#### 3.2.1 Improved Glycemic Control

Large meta-analyses and Randomized Controlled Trials (RCTs) consistently show that using wearable Continuous Glucose Monitoring (CGM), especially real-time systems, leads to a statistically significant reduction in HbA1c (0.4% - 1.0%) compared to Self-Monitoring of Blood Glucose (SMBG). This benefit is observed in both type 1 and type 2 diabetes patients, including those on intensive and non-intensive insulin therapy (Beck et al., 2019; Lind et al., 2020).

#### 3.2.6 Reduction in Hypoglycemia

The ability to monitor glucose trends and provide proactive hypoglycemia alerts significantly reduces the duration and incidence of hypoglycemic events, particularly nocturnal and asymptomatic hypoglycemia (Heinemann et al., 2020).

#### 3.2.7 Increased Patient Satisfaction and Quality of Life

Studies report a reduction in hypoglycemia-related anxiety, higher user satisfaction due to convenience and fewer fingersticks, and an overall improvement in diabetes-related quality of life (Petersson et al., 2022).

#### 3.2.8 Enhanced Adherence

The ease of use and continuous feedback provided by wearable CGM improve patient adherence to monitoring protocols compared to SMBG (Lee et al., 2024).

#### 3.2.9 Potential for Better Decision-Making

Continuous data empowers both patients and healthcare providers to make more timely and personalized therapy adjustments (Johnson, 2023).

## 3.3 The Future Prospects:

### 3.3.1 Truly Non-Invasive Sensors

Optical-based technologies (multi-wavelength spectroscopy, photoacoustics) and electromagnetic approaches (millimeter-wave sensing) are showing improved accuracy, reaching MARD <10% in preclinical trials. These advancements hold the potential to eliminate the need for calibration (Wang et al., 2025; Chen & Zhang, 2024).

### 3.3.2 Predictive AI Integration

The combination of deep learning algorithms with wearable data is enabling the prediction of hypoglycemia 30 minutes in advance with over 92% accuracy, and recommending personalized interventions (Zhu et al., 2024).

### 3.3.3 Multi-Parameter Platforms

There's ongoing development of integrated sensors for simultaneous monitoring of glucose, lactate, cortisol, and inflammatory biomarkers directly within microfluidics-based smartwatches (Kim et al., 2025).

### 3.3.4 Biodegradable Electronics

Research is progressing on implantable sensors made from biodegradable polymers (e.g., polylactate) that can degrade within the body after 60-90 days, thereby reducing infection risks (Gupta & Williams, 2024).

### 3.3.5 Energy Harvesting

**Piezoelectric nanogenerator technology** is being developed to convert kinetic energy from body movement into electrical power for wearable devices, potentially eliminating reliance on batteries (Li et al., 2023).

### 3.3.6 Advanced Artificial Pancreas Systems

The next generation of artificial pancreas systems will feature fuzzy logic algorithms that integrate CGM data, insulin pump control, and physical activity data for more sophisticated and personalized diabetes management (Grunberger et al., 2025).

## 4. DISCUSSION

Wearable devices have proven their worth as transformative tools in glucose monitoring, showing clear positive clinical impacts on glycemic control and the quality of life for diabetes patients. Minimally invasive electrochemical Continuous Glucose Monitoring (CGM) technology currently leads the market, offering high accuracy and reliability. However, its invasive nature (though minimal) and relatively high cost remain barriers for some patients and healthcare systems.

Optical and other non-invasive sensors hold great promise for a more comfortable and pain-free user experience. Yet, they generally still face significant challenges in terms of accuracy, precision, robustness against confounding factors (movement, temperature, hydration, skin color), and rigorous clinical validation compared to venous blood reference standards (Wang & Lee, 2025). Smartwatch-based technologies are particularly appealing due to their wide potential reach, but the validation of direct blood glucose accuracy from these platforms is still in early and controversial stages.

Integrating wearable data with smartphone applications and digital health platforms facilitates data visualization and feedback. Furthermore, applying AI and machine learning algorithms to the vast amounts of data from these devices paves the way for improved glycemic prediction, smarter early warning systems, and personalized closed-loop therapeutic recommendations, as already seen with artificial pancreas systems (Klonoff, 2023).

Other significant challenges include standardizing accuracy reporting (MARD remains a key metric, but context is crucial), ensuring equitable access, addressing data privacy and security concerns, and preparing healthcare providers to interpret and act upon the continuous flow of large datasets. Regulatory bodies (FDA, CE, and others) also need to continue adapting to the rapid pace of innovation in this space.

## 5. CONCLUSIONS

Wearable devices are revolutionizing diabetes management by providing real-time, minimally invasive, and patient-centric data. Their clinical impact has been proven to enhance glucose control and quality of life, while future innovations hold the potential to achieve more precise, automated, and integrated diabetes therapy. The primary challenges lie in accessibility, long-term accuracy, and integration with existing healthcare systems.

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