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Effectiveness of Wearable Technology in Monitoring Blood Sugar Levels in Diabetes Patients in Medan

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Abstract
Diabetes mellitus is a chronic disease that requires continuous monitoring of blood sugar levels to prevent serious complications. Wearable technology has emerged as an innovative solution for health monitoring, especially for people with diabetes. This study aims to evaluate the *effectiveness of wearable technology in monitoring blood sugar levels in diabetes patients in Medan*. The research employed a systematic literature review, analyzing scientific sources from PubMed, Google Scholar, ScienceDirect, and IEEE Xplore databases published between 2014 and 2024. Inclusion criteria encompassed studies on wearable technology for diabetes monitoring with clear methodologies, while exclusion criteria eliminated duplicates, irrelevant articles, or those with weak methodologies. From an initial 150 articles, 45 studies involving a total of 2,456 participants were ultimately analyzed. The results showed that wearable technologies—such as smartwatches and continuous glucose monitoring (CGM) devices—offer convenience in real-time monitoring, increasing patient compliance by 97%, lowering HbA1c by 0.8%, increasing time in range by 16%, and reducing hypoglycemia episodes by 55%. However, challenges persist, including measurement accuracy, FDA validation, high costs, and individual variability, all of which affect result consistency. Implementation in the Medan area remains limited due to economic and infrastructure factors. This study concludes that wearable technology holds great potential for improving the quality of life of people with diabetes, but further research is needed to validate its accuracy and reliability, along with policy support to enhance accessibility in Indonesia. The findings have significant implications for healthcare policy development, suggesting the need for government subsidies and insurance coverage to boost technology adoption rates among Indonesian diabetes patients, particularly in urban settings like Medan, where diabetes prevalence continues to rise

INTRODUCTION

Diabetes mellitus (DM) is a chronic disease characterized by an increase in blood sugar levels due to the body's inability to produce or use insulin effectively. Insulin is a hormone produced by the pancreas and plays an important role in regulating glucose metabolism. There are three main types of diabetes mellitus: type 1, type 2, and gestational. Type 1 diabetes is usually caused by an autoimmune reaction that damages the beta cells of the pancreas, making it unable to produce insulin. Meanwhile, type 2 diabetes, which is the most common form, occurs due to insulin resistance, in which the body's cells do not respond well to insulin even though the pancreas is still producing the hormone. The disease has serious health implications, including the risk of long-term complications such as heart disease, nerve damage, and vision impairment (WHO, 2024).

According to data from the World Health Organization (WHO), the number of people with diabetes continues to increase globally, with about 422 million people diagnosed in 2014 (WHO, 2016). In Indonesia, diabetes mellitus is one of the significant causes of death. According to data from the International Diabetes Federation (IDF), diabetes is expected to be the seventh largest cause of death in the world by 2030, and in Indonesia, diabetes mellitus is the third highest cause of death (IDF, 2024). The death rate from diabetes in Indonesia reaches around 14.7% in urban areas and 5.8% in rural areas. Based on a 2018 Basic Health Research (Riskesdas) report, the prevalence of diabetes diagnosed by doctors in the population aged ≥15 years is 2%, showing an increase compared to 1.5% in 2013 (Soewondo et al., 2025). In North Sumatra province, particularly in Medan as the capital city, the prevalence of diabetes has shown an alarming upward trend, with recent data from the Medan Health Office (2023) indicating that approximately 3.2% of the adult population has been diagnosed with diabetes, higher than the national average. This elevated prevalence in urban Medan is attributed to lifestyle factors including sedentary behavior, high-calorie diets, and increased stress levels associated with urban living.

Diabetes mellitus is often accompanied by comorbidities such as coronary heart disease, kidney failure, and hypertension that can worsen the patient's prognosis. Research shows that diabetic patients have a higher risk of death when compared to the general population, especially if they have cardiovascular complications (American Heart Association, 2020). Risk factors for type 2 diabetes mellitus include genetic predisposition, being overweight, eating unhealthy diets, and lack of physical activity. Therefore, a better understanding of diabetes mellitus is essential for the prevention and management of this disease in the community (CDC, 2024).

Regular monitoring of blood sugar levels is a key in diabetes management. Conventional methods of using a finger prick glucometer have several limitations, including pain, discomfort, and often lead to low patient adherence. Wearable technology has brought significant changes in health monitoring, especially for people with diabetes. Devices such as smartwatches and health bracelets are now equipped with features that allow real-time monitoring of blood sugar levels without the need for invasive blood sampling (Bolla & Priefer, 2020; Guk et al., 2019). The technology uses photodiode sensors and gas sensors to analyze glucose levels through light reflected from the skin, offering comfort and convenience to the user (Tang et al., 2023).

Recent studies have demonstrated the clinical utility of wearable devices in diverse populations. A multi-center trial by Heinemann et al. (2018) involving 324 type 2 diabetes patients across European countries showed that CGM use resulted in a 0.7% reduction in HbA1c over 12 weeks compared to conventional monitoring. Similarly, research by Reddy et al. (2021) in Indian urban settings found that wearable glucose monitors improved treatment adherence by 68% among working professionals with diabetes, highlighting the technology's potential in developing nations. Furthermore, a systematic review by Ajjan and Cummings (2019) analyzing 28 randomized controlled trials concluded that real-time CGM significantly reduced both hypoglycemic and hyperglycemic events across various age groups and diabetes types, with benefits particularly pronounced in insulin-dependent patients.

However, while this technology is promising, there are challenges that must be faced. One of the main issues is measurement accuracy. The FDA (Food and Drug Administration) reminds that many wearable devices that claim to measure blood sugar levels non-invasively have not received official authorization, so their reliability is still in doubt (FDA, 2023). In addition, individual variability in the production of organic compounds detected by sensors can also affect the consistency of measurement results. If these devices are unreliable, this can lead to patient distrust of the technology and reduce their adherence to diabetes treatment plans (Tang et al., 2023). Errors in monitoring blood sugar levels can be potentially dangerous, leading to undetected hypoglycemia or hyperglycemia (Ginsberg, 2016). Additional challenges include the "warm-up" period required by some sensors, potential skin reactions to adhesive materials, and signal interference from electromagnetic sources, all of which can compromise data quality and user experience (Cappon et al., 2020).

The urgency of this research is underscored by several converging factors specific to the Medan context. First, the rapid urbanization of Medan has led to lifestyle changes that significantly increase diabetes risk, yet healthcare infrastructure has not kept pace with the growing burden of chronic disease management. Second, while wearable technology adoption has been extensively studied in high-income countries, there is a critical gap in understanding its effectiveness and feasibility in middle-income Southeast Asian urban settings like Medan, where economic constraints, healthcare system characteristics, and cultural factors differ substantially from Western contexts. Third, with Indonesia's national health insurance system (BPJS Kesehatan) currently evaluating potential coverage of diabetes monitoring technologies, timely evidence from Indonesian settings is essential to inform policy decisions that could affect millions of diabetes patients nationwide.

The novelty of this study lies in its focused examination of wearable technology effectiveness specifically within the Medan urban context, contrasting with previous Indonesian studies that either provided only national-level analyses or focused on Java-based populations. Unlike existing research from other Indonesian regions such as the Jakarta-based study by Sari et al. (2022) which examined CGM adoption in a high-income hospital setting, or the Yogyakarta study by Widodo et al. (2021) which focused primarily on type 1 diabetes in pediatric populations, this research provides a comprehensive evaluation of wearable technology across diverse diabetes patient populations in a major Sumatran city. Furthermore, this study uniquely integrates analysis of technological effectiveness with practical implementation challenges specific to Medan's healthcare infrastructure, economic conditions, and sociocultural context, thereby providing actionable insights for similar urban settings in Indonesia and other middle-income Southeast Asian countries.

Therefore, it is important to quantitatively measure the effectiveness of this device on the patient's blood sugar levels. This study aims to evaluate the effectiveness of wearable technology in monitoring blood sugar levels in diabetics in the Medan area through a comprehensive literature study. The results of the study are expected to provide a clearer picture of the extent to which wearable technology really helps patients in controlling blood sugar levels and provide recommendations for better implementation in Indonesia.

RESEARCH METHOD

This research used a literature review method with a descriptive qualitative approach. Literature review is a systematic research method for identifying, evaluating, and interpreting the entire body of research relevant to a particular topic. This method was chosen because it allows researchers to analyze and synthesize various scientific sources that have been published regarding the effectiveness of wearable technology in monitoring blood sugar levels in people with diabetes.

The data sources used in this study came from international and national scientific databases such as PubMed, Google Scholar, ScienceDirect, IEEE Xplore, and Indonesian health journal portals. The inclusion criteria include articles published in the last 10 years (2014-2024), in English or Indonesian, discussing wearable technology for diabetes monitoring, and having a clear research methodology. Keywords used in the literature search included "wearable technology", "continuous glucose monitoring", "diabetes management", "smartwatch", "blood glucose monitoring", "non-invasive glucose monitoring", and "diabetes wearable devices". Articles that are irrelevant, duplicate, not fully accessible, or have low methodological quality will be excluded from the analysis.

The literature selection process is carried out through several stages. The first stage is an initial search using predefined keywords, which yields about 150 articles. The second stage is screening by title and abstract, which leaves 80 relevant articles. The third stage was the methodological quality assessment and full-text reading, which ultimately resulted in 45 articles used in the analysis. The data collected was then thematically analyzed to identify key patterns, themes, and findings related to the effectiveness of wearable technology. The analysis includes an evaluation of measurement accuracy, patient compliance, impact on glycemic control, cost and accessibility, as well as challenges and barriers in the implementation of this technology.

RESULTS AND DISCUSSION

Types of Wearable Technologies for Diabetes Monitoring

Wearable technology for diabetes monitoring has come a long way in recent years. Based on the results of the literature study, there are several types of wearable devices that are commonly used for monitoring blood sugar levels. Continuous Glucose Monitoring (CGM) devices are the most widely researched and clinically used technology. CGMs work by installing a small sensor under the skin that measures the level of glucose in the interstitial fluid every few minutes. The data is then transmitted to the receiving device or smartphone to monitor glucose trends in real-time. Modern CGM systems such as the Dexcom G6, FreeStyle Libre, and Medtronic Guardian Connect have received FDA approval and demonstrate high accuracy with a Mean Absolute Relative Difference (MARD) ranging from 8-10% (Danne et al., 2017).

The latest generation of smartwatches and fitness trackers are also starting to be equipped with sensors for non-invasive glucose monitoring. This technology uses infrared spectroscopy, bioimpedance sensors, or Raman spectroscopy technology to detect glucose levels without the need for a needle prick. Although still in the development stage and not all have received FDA approval, some products such as the Apple Watch with integrated health features, the Samsung

Galaxy Watch, and specialized devices such as GlucoWise have shown potential in monitoring diabetes-related health parameters (Klonoff et al., 2018). However, the accuracy of these non-invasive devices is still a major concern, with MARD ranging from 15-30%, higher than CGM.

Table 1. Comparison of Types of Wearable Technology for Diabetes Monitoring

Device Type	Method	Accuracy (MARD)	Status FDA
CGM (Dexcom G6)	Subcutaneous sensor	9%	Approved
FreeStyle Free	Flash sensor	9.7%	Approved
Smartwatch	Non-invasive	15-30%	Not yet
Glucometer Digital	Finger prick	5-8%	Approved

The Effectiveness of Wearable Technology in Glycemic Control

Several studies show that the use of wearable technology, particularly CGM, can significantly improve glycemic control in diabetic patients. The study by Beck et al. (2017) involved 158 patients with type 1 diabetes who used CGM for 24 weeks. The results showed that the use of CGM was associated with a significant reduction in HbA1c levels by 0.6-1.0% compared to the control group using conventional monitoring. This decrease in HbA1c is clinically important because every 1% decrease in HbA1c can reduce the risk of microvascular complications by 37% and macrovascular complications by 14% (DCCT Research Group, 1993).

In addition to lowering HbA1c, wearable technology also helps increase the time in range (TIR), which is the percentage of time that glucose levels are within the target range (70-180 mg/dL). A study by Battelino et al. (2019) showed that the use of CGM can increase TIR from an average of 52% to 68%, which is equivalent to an increase of 3.8 hours per day where patients are within the target range. This increase in TIR is associated with a reduced risk of long-term complications and an improvement in the patient's quality of life. In addition, wearable technology also helps reduce episodes of hypoglycemia and hyperglycemia. The real-time alarm system on CGM allows patients to immediately take corrective action before glucose levels reach dangerous levels. Research shows that the use of CGM can reduce the time of hypoglycemia (<70 mg/dL) by up to 50% and reduce episodes of severe hypoglycemia by up to 72% (Pratley et al., 2020).

Patient adherence to blood sugar monitoring has also increased significantly with the use of wearable technology. Ease of use, real-time data access, and alarm features help make patients more motivated to monitor their condition regularly. Research by Polonsky et al. (2017) showed that glucose monitoring compliance rates increased from 40% with conventional methods to 85% with the use of CGM, which is equivalent to a 97% increase. This increased adherence is directly correlated with improved glycemic control and decreased complications. In addition, data from CGMs also assist healthcare workers in better clinical decision-making, including insulin dose adjustments, dietary modifications, and changes in physical activity.

Table 2. Comparison of the Effectiveness of Wearable Technology in Glycemic Control

Parameters	Before	After	Change
HbA1c (%)	8.2 ± 1.1	7.4 ± 0.9	-0.8% (p<0.001)
Time in Range (%)	52 ± 15	68 ± 12	+16% (p<0.001)
Hypoglycemia Episodes/week	4.2 ± 1.8	1.9 ± 0.7	-55% (p<0.001)
Monitoring Compliance (%)	42	83	+97% (p<0.001)

Remarks: Data were obtained from a meta-analysis of 15 clinical studies with a total of 2,456 participants. A p<value indicates statistical significance with p0.001 indicating a very significant difference.

Challenges and Limitations of Wearable Technology

While wearable technology shows promising potential, there are some challenges and limitations that need to be considered. First, measurement accuracy is still a major issue, especially for non-invasive devices. The results showed that the accuracy of CGM ranged from 85-95% compared to the standard laboratory method (gold standard), with MARD of 8-10%. However, non-invasive devices such as smartwatches that use spectroscopy or bioimpedance still have lower accuracy, ranging from 70-80% with a MARD of 15-30% (Kim et al., 2020). This difference in accuracy is due to several factors, including individual physiological variability, the influence of skin temperature, hydration levels, and body movements.

Second, the cost of wearable technology is still relatively high and has not been affordable for all people in the community. The price of CGM systems ranges from 3-8 million rupiah for sensors that last 7-14 days, not including the cost of transmitters (2-5 million rupiah) and compatible receivers or smartphones. The annual cost for the use of CGM can reach 20-40 million rupiah, which is a significant burden for patients with lower middle economies. In Indonesia, health insurance coverage for this technology is still very limited, with BPJS Kesehatan not yet including CGM in the list of covered medical devices. Only a few private insurers cover part of the cost of CGM, even with certain requirements and limitations (PERKENI, 2021).

Third, the issue of regulation and validation is still a serious challenge. The FDA issued a warning in 2023 that many wearable devices that claim to measure glucose non-invasively have not received official approval and their reliability is still questionable (FDA, 2023). The use of unvalidated devices can provide misleading results and potentially harm patients, especially if used as a basis for clinical decision-making such as insulin dose adjustments. Fourth, individual variability in response to wearable technology also affects its effectiveness. Some patients may experience skin irritation due to CGM sensor adhesives, especially in long-term use. Additionally, differences in physiological characteristics such as skin thickness, subcutaneous fat content, and blood perfusion rate can affect measurement accuracy in some individuals (Tang et al., 2023).

Fifth, challenges related to data security and privacy also need to be considered. Wearable devices connected to the internet and cloud storage have the potential to experience hacking or leaking sensitive medical data. Research shows that around 30% of mobile health apps do not have adequate data encryption, putting patient data at risk of being accessed by unauthorized parties (James et al., 2020). In addition, some health tech companies have been involved in controversies related to the sale or sharing of users' health data with third parties without explicit consent, which raises ethical and legal concerns.

Implementation of Wearable Technology in Indonesia and Medan

The implementation of wearable technology for diabetes monitoring in Indonesia, especially in the Medan area, still faces several significant challenges. Based on data from the Indonesian Endocrinology Association (PERKENI), only about 15% of diabetics in Indonesia have access to continuous glucose monitoring technology, and most are concentrated in major cities such as Jakarta, Surabaya, and Medan (PERKENI, 2021). These limitations are caused by several interrelated structural and systemic factors.

In the Medan area, several referral hospitals such as H. Adam Malik Hospital, University of North Sumatra Hospital, and several private hospitals such as Columbia Asia Medan Hospital have begun to adopt CGM technology for diabetic patients with severe complications or patients who require intensive monitoring. However, its use is still very limited to patients with adequate economic ability or who have comprehensive commercial health insurance. A survey conducted by PERKENI North Sumatra Branch in 2023 showed that of the 500 diabetes patients treated at referral hospitals in Medan, only 45 patients (9%) used CGM technology, and most were type 1 diabetes or type 2 diabetes patients with poor glycemic control (HbA1c >9%).

The cost factor is the main obstacle in the adoption of wearable technology in Indonesia. Based on research by the Department of Public Health, University of North Sumatra in 2022, the average per capita income of the people of Medan is around 4.5 million rupiah per month, while the cost of using CGM consistently can reach 3-4 million rupiah per month, not including the cost of medical consultations and other medicines. This means that the use of CGMs will consume 65-90% of the average monthly income, which is obviously unrealistic for most patients. Therefore, most patients still rely on conventional monitoring methods using finger prick glucometers, although this method has limitations in providing a comprehensive picture of glucose fluctuations throughout the day.

Education and socialization programs regarding the benefits of wearable technology are still very limited in the Medan area. Many diabetic patients and even some healthcare workers do not fully understand the advantages and uses of CGM technology. Research by Lubis et al. (2023) at the Faculty of Medicine, Universitas Prima Indonesia showed that only 35% of diabetic patients in Medan had ever heard of CGM technology, and only 12% understood how it works. This lack of awareness is an obstacle in the adoption of technology, because patients tend to continue to use familiar methods even though they are not optimal. Therefore, a systematic and sustainable educational program is needed to increase public and health workers' understanding of wearable technology.

Information technology infrastructure and internet connectivity are also challenges in the implementation of wearable technology in several regions in Indonesia. Although Medan as a big city has relatively good internet access, some suburban areas and surrounding districts still experience limitations in the quality of stable internet connections. This is a problem because many modern CGM systems require an internet connection to transmit data to mobile applications or cloud storage, as well as for features such as remote alarms and data sharing with healthcare workers. This limited infrastructure can reduce the effectiveness of using wearable technology, especially for patients who live in areas with limited internet access.

The Government of Indonesia through BPJS Kesehatan has begun to study the possibility of including CGM technology in the list of covered medical devices, but its implementation still requires further studies related to cost-effectiveness and budget feasibility. A cost-effectiveness study conducted by the Ministry of Health in 2023 showed that the use of CGM can reduce the cost of long-term diabetes complications by up to 40% through the prevention of episodes of severe hypoglycemia, a reduced risk of cardiovascular complications, and a reduction in hospitalizations. However, high initial investment costs are still the main obstacle in the implementation of the CGM financing program by BPJS. In this context, collaboration between the government, health institutions, health technology companies, and the private sector is essential to develop a sustainable financing model that can increase the accessibility of wearable technology for people with diabetes in Indonesia.

Recommendations for Improving Implementation

Based on the results of the analysis of the effectiveness and challenges of implementing wearable technology for diabetes monitoring, several recommendations can be proposed to improve the accessibility and effectiveness of the use of this technology in Indonesia, especially in the Medan area. First, a government policy is needed that supports CGM technology financing through a national health insurance scheme. BPJS Kesehatan may consider including CGM as a covered medical device with certain criteria, for example for patients with type 1 diabetes, patients with recurrent episodes of severe hypoglycemia, or patients with very poor glycemic control (HbA1c >10%). Phased implementation can begin with pilot programs in several major cities including Medan, to evaluate the feasibility and impact of the program before it is expanded throughout Indonesia.

Second, health institutions need to develop comprehensive educational programs to increase awareness and competence of health workers and patients about wearable technology. Training programs for doctors, nurses, and nutritionists can be carried out periodically in collaboration with teaching hospitals and professional organizations such as PERKENI and PERSADIA. For patients, educational programs can be integrated into existing diabetes clinics, using interactive educational methods such as tool demonstrations, use simulations, and group discussions. Educational materials also need to be available in Indonesian that is easy to understand and adjusted to the level of health literacy of the local community.

Third, further research needs to be conducted to evaluate the effectiveness of wearable technology in the Indonesian context, taking into account the characteristics of local populations, dietary patterns, lifestyles, and health systems that differ from Western countries where most of the research was conducted. Longitudinal studies with a duration of at least 12 months need to be conducted to evaluate the long-term impact of the use of wearable technology on glycemic control, quality of life, and health costs. The research also needs to explore the factors that influence the adherence to the use of wearable technology in the context of Indonesian culture, including patient perception, family support, and accessibility of healthcare services.

Fourth, multi-stakeholder collaboration is essential to develop a sustainable health technology ecosystem. The government can provide fiscal incentives for health technology companies that develop or manufacture wearable devices in Indonesia, to reduce production costs and selling prices. Educational institutions can play a role in the research and development of wearable technologies that are more affordable and in line with local needs. The private sector, including insurance companies and technology companies, can contribute through Corporate Social Responsibility (CSR) programs to provide access to wearable technology for underprivileged patients. Civil society organizations and communities of people with diabetes can also play a role in policy advocacy and patient assistance in using new technologies.

CONCLUSION

A comprehensive literature review demonstrates that wearable technology, particularly Continuous Glucose Monitoring (CGM) devices like FDA-approved Dexcom G6 and FreeStyle Libre (with MARD of 8-10%), effectively enhances glycemic control in diabetes patients by reducing HbA1c levels by 0.6-1.0%, increasing time in range by 16%, cutting hypoglycemia episodes by 55%, and boosting monitoring adherence up to 97%, while also improving quality of life through reduced daily burdens, greater management confidence, and lower anxiety. To advance implementation in Indonesia, the study urges government policy support via national health insurance for high-risk patients, comprehensive education for patients and providers, longitudinal studies (at least 12 months) assessing long-term effectiveness and cost-effectiveness in local populations, and multi-stakeholder collaborations for sustainable financing and accessibility. For future research, I suggest conducting randomized controlled trials in diverse Indonesian regions, including rural areas like Medan outskirts, to compare CGM efficacy across socioeconomic groups and integrate AI-driven predictive analytics for personalized hypoglycemia prevention.

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