Journal of Health Informatics in Developing Countries
http://www.jhidc.org/
Vol. 17 No. 1, 2023

Submitted: Jan 12th, 2023 Accepted: April18th, 2023

A Systematic Review of Machine Learning and Artificial Intelligence for Diabetes Care

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Abstract

Diabetes is a chronic health condition that affects millions of people worldwide, causing significant morbidity and mortality. The prevalence of diabetes is expected to continue rising, making it crucial to develop effective strategies for prevention, early detection, and management. In recent years, machine learning (ML) and artificial intelligence (AI) have emerged as powerful tools in the management of diabetes, with significant applications in automated retinopathy detection, clinical decision support, predictive population risk stratification, and self-management tools for patients. This systematic literature review provides a comprehensive overview of the current state-of-the-art AI and ML-led techniques being used to manage diabetes. The review categorizes and analyzes relevant works in each of the four key areas of diabetes care. It examines the advantages and limitations of using AI and ML in diabetes management and highlights areas where further research is needed. Overall, the review shows that AI and ML have the potential to revolutionize the way diabetes is managed, enabling more accurate and efficient detection, diagnosis, and treatment of the disease. However, the review also points out that further research is needed to address challenges such as data quality, system transparency, and ethical considerations. The review provides valuable insights for researchers, healthcare providers, policymakers, and patients interested in using AI and ML to improve diabetes care.

Keywords: Machine Learning; Artificial Intelligence; review; Diabetes care.

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1. Introduction

Diabetes is a chronic condition characterized by high levels of glucose in the blood. It can result from inadequate production or insufficient utilization of insulin (WHO, 2021). the hormone responsible for regulating glucose uptake by cells in the body, particularly muscle and fat cells. Without enough insulin, cells cannot absorb glucose effectively, disrupting its normal utilization (Sharma et al., 2022).The International Diabetes Federation (IDF) reports that approximately 463 million individuals between the ages of 20 and 79 have diabetes, and an additional 374 million have impaired glucose tolerance (IDF, 2019). It is estimated that by the year 2045, the number of people with diabetes will increase to 693 million (Cho et al., 2018). In 2017, the global diabetes prevalence was 8.8%, and it is projected to rise to 10% by 2045 (Cho et al., 2018).

Diabetes is a serious health condition that can lead to multiple complications, causing significant morbidity and mortality (IDF, 2019). Thus, it is crucial to intervene early, not only for treatment but also for prevention and timely detection of the disease. Managing diabetes is a difficult task, given that half of adults with diabetes are unaware they have it, despite the fact that diabetes accounts for 10% of global health expenditure, amounting to US$760 billion (who,2021).

Diabetes can be classified into three main categories: type 1 diabetes (T1D), type 2 diabetes (T2D), and gestational diabetes (GDM) (IDF, 2021). T1D affects approximately 8% of individuals with diabetes, and it occurs when the body produces insufficient or no insulin, requiring insulin injections for treatment. T1D can affect people of any age, but it is most commonly found in children and young adults [5]. T2D, on the other hand, accounts for about 90% of all diabetes cases and is usually diagnosed in elderly individuals. It is characterized by insulin resistance (Kumari & Ahlawat, 2021). Lastly, GDM is a type of diabetes that occurs during pregnancy and typically resolves shortly after delivery (Hamlin, 2012).

DM can be diagnosed manually by a healthcare professional or automatically using a device. Both approaches have advantages and disadvantages. Manual diagnosis enables a healthcare professional to use their expertise without relying on a machine for DM detection. However, in the early stages of DM, the symptoms may be subtle and difficult to identify, even for an experienced doctor. Advances in machine learning and artificial intelligence have made automated DM detection and diagnosis more effective and efficient than manual methods (Sharma and Singh, 2018; Afzali and Yildiz, 2018; Theera-Umpon et al., 2019). Automated systems reduce the workload for medical practitioners and minimize the risk of human error. High-quality data is essential for efficient diagnosis, profitable management, and informed decision-making based on patient reports. Therefore, computer-based support systems play a crucial role in DM management (Theera-Umpon et al., 2019).

Artificial Intelligence (AI) refers to the development and theory of virtual systems that can perform

tasks requiring human intelligence, such as visual perception, speech recognition, decision-making, and language translation (Rajiv et al., 2019).These systems can use simple rule-based approaches or more complex statistical methods. Machine learning (ML) is a subset of AI that enables systems to learn and improve automatically from experience without the need for explicit programming (Rajiv et al., 2019; (Brown, 2021). Machine learning can be supervised, unsupervised, semi-supervised, or reinforcement-based (Hosseini et al., 2020). Through deep learning, machines aim to replicate human intelligence by simulating the structure of the human brain using recurrent neural networks (Kavakiotis et al., 2017). AI/ML tools have transformed businesses worldwide and are extensively used across scientific fields.

In recent years, the use of machine learning and artificial intelligence has become increasingly prevalent in the management of diabetes and its associated complications. This systematic literature review aims to provide a comprehensive overview of the current AI and ML-led techniques being used to manage the disease. AI and ML have significant applications in four key areas of diabetes care, including automated retinopathy detection, clinical decision support, predictive population risk stratification, and self-management tools for patients [15,16]. (Dankwa-Mullan et al., 2019; van Gemert-Pijnen et al., 2011).

Given the vast and complex literature on diabetes management with different AI and ML-based tools, this article seeks to categorize and review the most relevant works. Our goal is to present a clear and concise overview of the latest scientific advancements in the field of diabetes management, specifically utilizing machine learning and artificial intelligence.

2. Methods

A systematic literature review was conducted to identify relevant studies on the use of machine learning and artificial intelligence for the management of diabetes. The Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines were followed to ensure a rigorous and transparent search process. To minimize the risk of bias, the search strategy was designed by JP and included the MEDLINE, Web of Science, PubMed, Google Scholar, and Web of Science databases. Reference lists of included studies were also hand-searched to identify additional studies that met the predefined inclusion criteria. The search was limited to studies published between January 2015 and December 2022, and the following search terms were used: "diabetes," "diabetes care," "machine learning," and "artificial intelligence." Studies that focused on deep learning or other diseases were excluded from the review. The inclusion criteria for the studies were that they reported the use of ML or AI in the management and care of diabetes. The aim of this review is to present a clear and comprehensive overview of the current state of science in the field of diabetes management using machine learning and artificial intelligence.

2.1 Eligibility Criteria

i. Inclusion Criteria

This study explores the application of artificial intelligence and machine learning in the management and care of diabetes. For this systematic review, the inclusion criteria consist of studies that:

- Are published in the English language;
- Are published between the years 2015 and 2022;
- Investigate diabetes;
- Use at least one of the artificial intelligence, and machine learning techniques;

ii.Exclusion Criteria

- Included other diseases in addition to diabetes
- Published before January 2015 and after December 2022
- Published in a language other than English

3. Results

The systematic review of studies evaluating the diagnosis and treatment of refractive errors using AI and ML conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidance identified 58 studies. The detailed search strategy for the review is explained in detail in graph 1. Furthermore, a summary of included studies is presented in table 1 and the findings were evaluated to identify themes that frequently emerged during the systematic review.

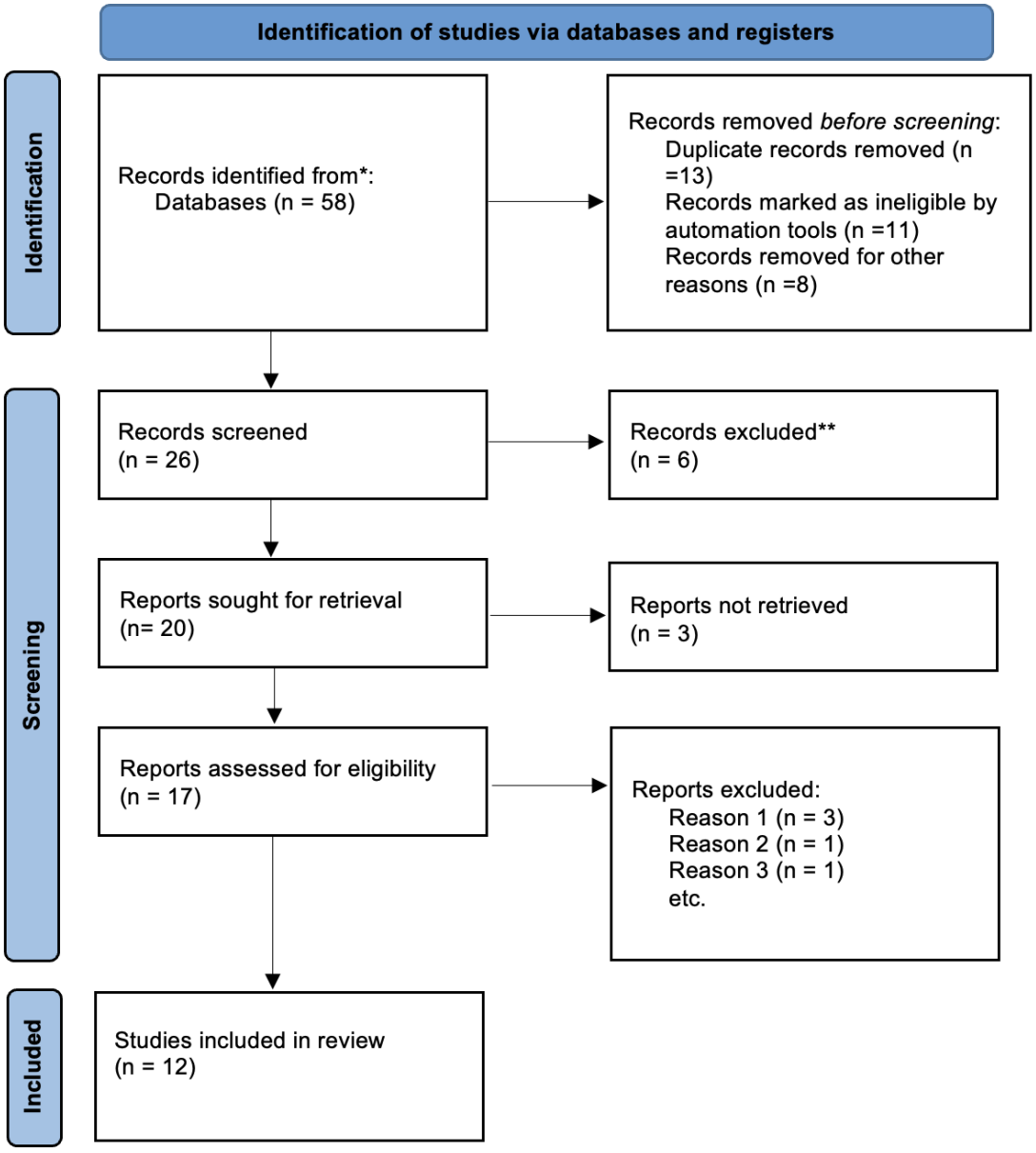

Figure 1. Summary of review strategy – The PRISMA Flow Diagram

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

3.1. Machine learning algorithms and their application in diabetes care

Machine learning (ML) algorithms have various applications in healthcare, particularly in diabetes care. There are four main categories of ML algorithms, namely supervised learning, unsupervised learning, semi-supervised learning, and reinforcement learning (Hosseini et al., 2020; Qaraqe et al., 2021).

Supervised learning is a powerful data analysis approach in which the system learns from labeled data to map an input to an output. In diabetes care, supervised learning algorithms can be used to predict

patient outcomes based on specific inputs such as age, gender, blood glucose levels, and other clinical factors. For example, a study developed a predictive model for diabetic retinopathy using a supervised learning algorithm (Bhatia et al., 2016). The model accurately classified diabetic retinopathy fundus images using convolutional neural networks. Unsupervised learning is used when there are no pre-existing labels or specifications. This type of learning can be useful in diabetes care to uncover hidden data structures or relationships between variables (Tuppad & Patil, 2022). For example, clustering can be used to identify groups of patients with diabetes who share similar clinical histories and characteristics. This information can help healthcare providers tailor treatments and interventions for specific patient groups. Another example is dimensionality reduction, which can be used to identify important features in large datasets, such as genetic data, to improve diabetes risk prediction models (Akyol et al., 2016).

Semi-supervised learning is a combination of supervised and unsupervised learning methods, and is particularly useful when there is a limited amount of labeled data available. In diabetes care, semi-supervised learning can be used to develop predictive models using a combination of labeled and unlabeled data (Tuppad & Patil, 2022). For instance a study developed a diabetic predictive model using the Laplacian support vector machine (LapSVM) algorithm (Akyol et al., 2016). The model used both labeled and unlabeled data to improve the accuracy of the predictions.

Reinforcement learning is a reward- or penalty-based method that aims to maximize the reward or minimize the risk by exploring different states and making the most proper decisions. In diabetes care, reinforcement learning can be used to develop personalized interventions to improve patient outcomes. Research studies have shown that machine learning algorithms such as Q-learning agents can be used by physicians to recommend insulin doses based on factors such as patients' body mass index (BMI), activity level, alcohol usage status, and current HbA1c level (Qaraqe et al., 2021). By leveraging this machine learning model, healthcare providers can achieve effective treatment doses in a more timely and efficient manner, thereby reducing the need for multiple dosage trials based solely on clinical acumen (Ngo et al., 2018). This approach not only leads to improved treatment efficacy time, but also has the potential to reduce patient stress resulting from fewer clinic visits, reduce healthcare costs, and improve overall quality of life (Qaraqe et al., 2021). By leveraging machine learning algorithms in diabetes care, healthcare providers can improve patient outcomes, while reducing the overall burden of care for both patients and providers (Oroojeni Mohammad Javad et al., 2019).

3.2. AI use diabetes management

AI-based medical devices have gained FDA approval in various medical fields, including radiology, cardiology, and oncology, but only a few have been approved for diabetes management

(Benjamens et al., 2020). Efforts towards the clinical application of AI in diabetes care can be categorized into four areas: automatic retinal screening, clinical diagnosis support, patient self-management tools, and risk stratification (Nomura et al., 2021).

The first category is automatic retinal screening, where an AI system interprets fundus images to diagnose diabetic retinopathy. The IDx-DR device is an example of this technology and has been approved by the FDA (Abràmoff et al., 2018). The device enables screening and diagnosis in rural areas where accessing an ophthalmologist may be difficult. There is a vast amount of patient health records and recent research available that can be leveraged to create an up-to-date knowledge base for diabetes patients, doctors, researchers, and clinicians. With the ability to quickly analyze and interpret massive amounts of data, AI has the potential to enhance the screening, diagnosis, and management of diabetes patients, according to several published studies (López et al., 2018).

It has been demonstrated that deep learning artificial neural networks (ANNs) have the ability to accurately identify diabetic retinopathy and diabetic macular edema in retinal fundus images with high sensitivity and specificity. A team of researchers has developed an algorithm that utilizes the intensity of pixels in a fundus image to determine the severity of diabetic retinopathy. The algorithm was trained using a large dataset and evaluated at two different operating points, one for high specificity and the other for high sensitivity, resulting in exceptional scores. (Rigla et al., 2017)

The second category is clinical diagnostic support, where AI technologies are being developed to mimic the treatment recommendations of specialists. Advisor Pro is an FDA-approved system that uses AI to propose adjustments to insulin dosage remotely based on information obtained from CGM and SMBG. Clinical trials have shown that the system's efficacy is comparable to diabetes specialists (Nimri et al., 2020).

The third category is patient self-management tools that use AI to interpret biometric data and alert patients to improve their blood glucose control. The Guardian Connect System is an example of this technology, and it can predict hypoglycemic attacks and alert patients accordingly.

The fourth category is prediction and risk stratification, which could be part of preemptive medicine. Statistical models such as logistic regression, Cox proportional hazard model, or Weibull distribution analysis have been used to predict the onset of diabetes within 5 to 10 years with an accuracy of around 0.74 to 0.94 in the C-index (Abbasi et al., 2012). This technology could help identify individuals highly likely to develop diabetes and intervene at an early stage to prevent its incidence (Zou et al., 2018). ML methods are frequently utilized for prediction (when the outcome variable is a value) or classification (when the outcome variable is a class) (Contreras & Vehi, 2018). These methods can also be applied to

diabetes care for tasks such as disease probability prediction, screening, diagnosis, treatment guidance, and complication management (Abhari et al., 2019).

Currently, AI-powered predictive modeling is capable of identifying diabetes populations with the highest risk of preventable complications, thus reducing the frequency of emergency department visits, admissions, and readmissions (Han et al., 2015). This technology is utilized by larger healthcare systems, physician groups, and health plans to analyze vast amounts of digital and unstructured patient data, proactively identifying and characterizing diabetes populations, pinpointing patients at risk of diabetic comorbidities, and determining which patients may benefit from specialized diabetes disease management programs (Shankaracharya et al., 2012).

Table (1) Summary of Included Studies

Author & Year of Publication	Title	Findings
Makroum, M. A., Adda, M., Bouzouane, A., & Ibrahim, H. (2022).	Machine Learning and smart devices for diabetes management: Systematic review.	Wearable devices have garnered significant attention in the healthcare industry for their potential to assist individuals with chronic conditions, such as diabetes. These devices have the capability to aid in the management of diabetes and mitigate the risk of associated complications.
Ellahham, S. (2020).	Artificial Intelligence: The future for diabetes care. *The American Journal of Medicine*, *133*(8), 895–900.	The trend of self-management for diabetes is on the rise, and artificial intelligence-based clinical decision support is proving beneficial for both patients and healthcare professionals involved in diabetes care.
Rajiv, S., Singla, A., Gupta, Y., & Kalra, S. (2019).	*Artificial Intelligence/machine learning in diabetes care*. Indian journal of endocrinology and metabolism.	AI/ML is revolutionizing various aspects of our lives, including healthcare. Its application in diabetes care has the potential to significantly expand the scope of diabetes management, making it more effective and efficient.
Nomura, A., Noguchi, M., Kometani, M., Furukawa, K., & Yoneda, T. (2021).	Artificial Intelligence in current diabetes management and prediction. *Current Diabetes Reports*, *21*(12).	With the availability of massive amounts of organized data and abundant computational resources, the predictive capabilities of AI are expected to greatly increase. This will lead to a significant enhancement in the accuracy of disease prediction models for diabetes.
Chauhan, T., Rawat, S., Malik, S., & Singh, P. (2021).	Supervised and unsupervised machine learning based review on diabetes care. *2021 7th International Conference on Advanced Computing and Communication Systems (ICACCS)*.	Supervised learning techniques have been successful in accurately predicting diabetes, while unsupervised learning techniques like PCA and K-Mean are useful in attribute selection and outlier detection from large datasets. A recent study shows that a combination of supervised and unsupervised machine learning techniques, such as K-Mean and SVM, can effectively diagnose and evaluate diabetes with high accuracy.
Dankwa-Mullan, I., Rivo, M., Sepulveda, M., Park, Y., Snowdon, J., & Rhee, K. (2019).	Transforming diabetes care through artificial intelligence: The future is here. Population Health Management, 22(3), 229–242. https://doi.org/10.1089/pop.2018.0129	The potential impact of AI applications on diabetes care is immense, with the ability to assist millions of people with diabetes in achieving better blood glucose control, reducing hypoglycemic episodes, and preventing diabetes-related comorbidities and complications. AI applications offer several advantages such as improved accuracy, efficiency, ease of use, and higher satisfaction for people with diabetes, as well as their clinicians, family, and caregivers.

Rigla, M., García-Sáez, G., Pons, B., & Hernando, M. E. (2017)	Artificial intelligence methodologies and their application to diabetes. *Journal of Diabetes Science and Technology*, *12*(2), 303–310.	The management of diabetes has undergone a significant transformation, requiring diabetologists to acquire skills from new domains to effectively manage the condition.
Abhari, S., Niakan Kalhori, S. R., Ebrahimi, M., Hasannejadasl, H., & Garavand, A. (2019).	Artificial intelligence applications in type 2 diabetes mellitus care: Focus on machine learning methods. *Healthcare Informatics Research*, *25*(4), 248.	The primary applications of AI in the care of type 2 diabetes mellitus have been for screening and diagnosis at various stages of the disease.
Tuppad, A., & Patil, S. D. (2022).	Machine learning for diabetes clinical decision support: A Review. *Advances in Computational Intelligence*, *2*(2).	This review comprehensively covers the various predictive modeling applications of machine learning in diabetes care, while also identifying the medical and technological gaps and outlining the different aspects involved in clinical decision support for diabetes using machine learning.
Qaraqe, M., Erraguntla, M., & Dave, D. (2021).	AI and Machine Learning in diabetes management: Opportunity, status, and challenges. *Multiple Perspectives on Artificial Intelligence in Healthcare*, 129–141.	It is becoming increasingly clear that leveraging advanced AI and machine learning algorithms can help address some of the long-standing health issues. Moreover, sudden spikes or drops in blood glucose levels can have serious and life-threatening consequences for people with diabetes.
Hosseini, M. M., Zargoush, M., Alemi, F., & Kheirbek, R. E. (2020).	Leveraging machine learning and big data for optimizing medication prescriptions in complex diseases: A case study in diabetes management. *Journal of Big Data*, *7*(1).	This study showcases how machine learning can aid in making optimal decisions in the face of complex problems, particularly those stemming from big data.
Schäfer, Z., Mathisen, A., Svendsen, K., Engberg, S., Rolighed Thomsen, T., & Kirketerp-Møller, K. (2021).	Toward machine-learning-based decision support in diabetes care: A risk stratification study on diabetic foot ulcer and amputation. *Frontiers in Medicine*, *7*.	Machine learning techniques have proven to be practical in identifying risk factors for predicting foot ulcers and amputation.

4. Discussion

The use of machine learning (ML) and artificial intelligence (AI) in diabetes management has significantly increased in recent years. This systematic literature review aims to provide a comprehensive overview of the current AI and ML-led techniques being used to manage the disease.

The review identified four key areas in diabetes care where AI and ML have significant applications: automated retinopathy detection, clinical decision support, predictive population risk stratification, and self-management tools for patients. These areas represent significant challenges in diabetes management, and the use of AI/ML tools has the potential to improve patient outcomes, reduce healthcare costs, and provide personalized care.

Automated retinopathy detection is a crucial area in diabetes management as it can identify and treat diabetic retinopathy (DR) at an early stage, reducing the risk of vision loss. AI/ML tools have shown promising results in automated DR detection by analyzing retinal images and detecting specific features related to DR. This approach has the potential to increase the efficiency and accuracy of DR screening, reducing the burden on healthcare professionals.

Clinical decision support systems (CDSS) can help healthcare professionals in making accurate and timely decisions about patient care. AI/ML algorithms can analyze patient data, including medical history, laboratory test results, and imaging studies, to provide personalized treatment recommendations.

CDSS has the potential to improve patient outcomes, reduce medical errors, and increase efficiency in diabetes management.

Predictive population risk stratification uses AI/ML algorithms to identify high-risk patients who are likely to develop complications related to diabetes. By analyzing patient data, including demographic factors, medical history, and lifestyle factors, AI/ML algorithms can identify patients who are at risk of developing complications and provide personalized care plans to reduce their risk (Sen et al., 2019).

Self-management tools for patients use AI/ML algorithms to provide personalized recommendations for diabetes management, including dietary and lifestyle changes, medication adherence, and physical activity. These tools can provide patients with real-time feedback, enabling them to make informed decisions about their diabetes management.

Another area where AI and ML have shown promising results is in population risk stratification. This involves using predictive analytics to identify individuals who are at high risk of developing diabetes or its associated complications. By analyzing large datasets and identifying risk factors, these algorithms can accurately predict the likelihood of an individual developing diabetes, allowing for targeted interventions and prevention strategies (Dankwa-Mullan et al., 2019). Additionally, these tools can be used to stratify patients based on their risk of developing specific complications, such as diabetic retinopathy, nephropathy, and neuropathy, allowing for earlier detection and management of these conditions (van Gemert-Pijnen et al., 2011).

Lastly, self-management tools for patients have been developed using AI and ML to provide personalized care to individuals with diabetes. These tools, such as mobile applications and wearable devices, can help patients monitor their glucose levels, track their diet and exercise, and receive personalized recommendations based on their data (Dankwa-Mullan et al., 2019). By empowering patients to manage their own care, these tools can improve patient outcomes and reduce the burden on healthcare providers.

In conclusion, AI and ML have revolutionized the way we approach diabetes management. With the increasing prevalence of diabetes worldwide, the use of these technologies is becoming increasingly important for prevention, diagnosis, and management of the disease. The applications of AI and ML in diabetes care are vast, ranging from automated retinopathy detection to self-management tools for patients. While challenges such as data quality and regulatory concerns remain, the potential benefits of these technologies cannot be ignored. Future research should focus on validating the effectiveness of these tools in real-world settings and addressing the ethical and social implications of their use in healthcare

5. Declarations

5.1 Conflict of Interest Statement

The authors have no conflict of interests to declare.

5.2 Funding Disclosure

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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