ZIAJOR, Seweryn, TOMASIK, Justyna, SAJDAK, Piotr, TURSKI, Mikołaj, BEDNARSKI, Artur, STODOLAK, Marcel, SZYDŁOWSKI, Łukasz, ŻUROWSKA, Klaudia, KRUŻEL, Aleksandra, KŁOS, Kamil and DĘBIK, Marika. The use of artificial intelligence in the diagnosis and detection of complications of diabetes. Journal of Education, Health and Sport. 2024;65:11-27. eISSN 2391-8306. https://dx.doi.org/10.12775/JEHS.2024.65.001
https://apcz.umk.pl/JEHS/article/view/49795
https://zenodo.org/records/10958564

The journal has had 40 points in Minister of Science and Higher Education of Poland parametric evaluation. Annex to the announcement of the Minister of Education and Science of 05.01.2024 No. 32318. Has a Journal's Unique Identifier: 201159. Scientific disciplines assigned: Physical culture sciences (Field of medical and health sciences); Health Sciences (Field of medical and health sciences).
Punkty Ministerialne 40 punktów. Załącznik do komunikatu Ministra Nauki i Szkolnictwa Wyższego z dnia 05.01.2024 Lp. 32318. Posiada Unikatowy Identyfikator Czasopisma: 201159. Przypisane dyscypliny naukowe: Nauki o kulturze fizycznej (Dziedzina nauk medycznych i nauk o zdrowiu); Nauki o zdrowiu (Dziedzina nauk medycznych i nauk o zdrowiu).
The authors declare that there is no conflict of interests regarding the publication of this paper.
Received: 28.03.2024. Revised: 28.03.2024. Accepted: 10.04.2024. Published: 11.04.2024.

The use of artificial intelligence in the diagnosis and detection of complications of diabetes

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Abstract

Introduction: Diabetes poses a significant global health challenge, impacting patient well-being and longevity. Despite advances in diagnosis and treatment, the prevalence of diabetes continues to rise, with projections indicating a substantial increase in affected individuals in the coming years. The complications of diabetes, including cardiovascular disease, retinopathy, nephropathy, and neuropathy, underscore the importance of early detection and management. In this context, artificial intelligence (AI) offers promising opportunities to revolutionize diabetes care, enabling faster diagnostics, more effective treatment strategies.

Description of the State of Knowledge: Artificial intelligence (AI) has emerged as a transformative force in healthcare, leveraging machine learning and deep learning algorithms to analyze vast amounts of medical data. These algorithms enable more accurate diagnosis, prediction of disease onset, and early detection of complications associated with diabetes. Machine learning models, including support vector machines and neural networks, have shown promise in identifying diabetes risk factors and predicting disease progression. Deep learning techniques, with their ability to analyze complex data patterns, offer further insights into diabetes diagnosis. Additionally, fuzzy cognitive maps provide a framework for decision-making based on patient data, enhancing early detection efforts.

Summary: Artificial intelligence holds immense potential to transform diabetes care, offering solutions for early detection, personalized treatment, and improved patient outcomes. By harnessing the power of AI algorithms, healthcare providers can enhance diagnostic accuracy, predict disease progression, and implement targeted interventions.

Keywords: Artificial intelligence, machine learning, deep learning, diabetes

Introduction

Diabetes represents a serious public health problem and significantly impacts the functioning and quality of life of patients, leading to increased morbidity and ultimately premature death [1]. Despite progress in diagnosis, treatment, and extending life expectancy in recent years, in 2021 alone, 537 million people worldwide were living with diabetes [2]. According to the International Diabetes Federation (IDF), the number of people with diabetes is expected to increase significantly in the coming years. Forecasts suggest that by 2030, there will be 643 million individuals affected, and by 2045, the number will rise to 783 million globally [3]. Diabetes is a metabolic disease characterized by elevated blood glucose levels, leading to the development of numerous macrovascular and microvascular complications [4,5]. Typical symptoms of diabetes include polyuria, excessive thirst, and unexplained weight loss [13]. Major consequences associated with prolonged elevated serum glucose levels include coronary heart disease (CHD), stroke, peripheral arterial disease (PAD), heart failure (HF), diabetic retinopathy (DR), diabetic nephropathy, and cardiac autonomic neuropathy (CAN) [5]. Cardiovascular disease (CVD) is the leading cause of morbidity and mortality in individuals with diabetes, occurring approximately 15 years earlier than in healthy individuals. Therefore, appropriate diagnosis, glycemic control, and diabetes treatment are fundamental in preventing disease complications and prolonging patients' lives [5]. The recent development of artificial intelligence (AI) has enabled significant progress in medical data analysis. By utilizing machine learning and deep learning, AI algorithms allow for better and more accurate analysis of medical data generated by patients with diabetes compared to human capabilities [6]. The application of artificial intelligence in diabetes diagnosis can increase the effectiveness of screening tests and enable earlier diagnosis, leading to targeted therapy implementation [7]. Implementing appropriate AI algorithms into closed-loop insulin delivery systems can result in fewer fluctuations in glucose levels, reducing morbidity, mortality, and improving patients' quality of life [6, 7]. Artificial intelligence technology can also be utilized for predicting and diagnosing diabetes complications, including retinopathy, neuropathy, and diabetic nephropathy [7].

Description of the state of knowledge

1.1. Artificial intelligence (AI) in medicine

Artificial Intelligence (AI) is a new and rapidly evolving field with the potential to transform many areas of society, including healthcare [8]. It refers to the development of computer systems capable of performing tasks that typically require human intelligence, utilizing machine learning (ML), deep learning (DL), and appropriate algorithms, AI enables faster diagnostics, more effective treatment, earlier detection of complications, and more efficient patient monitoring [9]. This technology is used to analyze large amounts of patient data and identify trends and patterns that may be difficult for physicians to detect, helping doctors manage their time more effectively and provide better care to their patients [8]. AI has created new medical possibilities and transformed diagnostic and therapeutic practices, allowing for greater treatment availability and optimization, cost reduction, and improved healthcare. Significant advancements and improvements in disease diagnostics and early intervention have been made through algorithms generated by artificial intelligence for clinical decision support systems and disease prediction. Artificial intelligence has also found application in clinical trials of new drugs, improving research on drug efficacy, interactions, and adverse effects [9]. The use of artificial intelligence in medicine is continually growing, with at least 29 AI algorithms and medical devices approved by the Food and Drug Administration (FDA) in various medical areas [10]. AI-based medical technologies are rapidly evolving towards suitable solutions for clinical practice. Deep learning algorithms excel in processing increasing amounts of medical data, making them applicable in an increasing number of medical specialities (Table 1) [11].

Specialization	The application of artificial intelligence
Cardiology	• smartphone-based ECG monitoring and detection of atrial fibrillation • predicting the risk of cardiovascular diseases based on electronic patient records • image analysis in echocardiography, cardiac CT, cardiac MRI and CT angiography
Diabetology	• continuous glucose monitoring • early detection of diabetes complications • automated insulin delivery systems
Nephrology	• prediction of the decline in glomerular filtration rate • assessment of the risk of progressive IgA nephropathy
Gastroenterology	• image analysis in endoscopy and USG • diagnosis of gastroesophageal reflux disease and atrophic gastritis • predict outcomes in gastrointestinal bleeding and inflammatory bowel disease
Neurology	• detection of generalized epileptic seizures • early detection of strokes, as well as their treatment and prognosis • quantitatively assess of gait, posture and tremor in patients with multiple sclerosis, Parkinson's disease, Parkinsonism and Huntington's disease
Pathology	• assessment of histopathological specimens
Radiology	• image analysis in radiography, mammography, ultrasound (US), computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography (PET)
Ophthalmology	• diagnosis of diabetic retinopathy, diabetic macular edema, age-related macular degeneration, glaucoma, retinopathy of prematurity, age-related and congenital cataracts, and retinal vein occlusion • image analysis in optical coherence tomography (OCT)
Dermatology	• differential diagnosis of selected skin lesions • image analysis in dermoscopy, high-frequency ultrasound, and reflectance confocal microscopy
Oncology	• predicting prognosis for patients with cancer based on histologic and/or genetic information • prediction the risk of complications before and recurrence risks after surgery for malignancie • treatment planning and predict treatment failure with radiation therapy • identification of DNA sequences in cancer cells

Table 1. Current Applications of Artificial Intelligence in Medicine. Original research [10, 11, 12].

1.2. Artificial intelligence in early detection of diabetes

Typical clinical symptoms of diabetes include increased thirst, polyuria (excessive urination), unintended weight loss, fatigue, blurred vision, and slow wound healing. However, in the early stages of the disease, most patients may not exhibit any symptoms, which poses diagnostic challenges. At this stage, diagnosis often occurs during routine blood tests, revealing prolonged asymptomatic hyperglycemia and the consequent development of complications [14]. Therefore, it is important to predict and diagnose diabetes early to avoid its negative consequences. To achieve this, the current technological advancements and the development of artificial intelligence can be utilized [15].

1.2.1. Machine Learning (ML)

It turns out that the use of machine learning can be a promising tool to increase the predictive efficiency of previously used standard statistical tools [16]. Among the methods and algorithms of machine learning that have been applied in diabetes diagnosis are support vector machine (SVM), artificial neural network, decision tree, naive Bayes classifier, random forest, k-nearest neighbors, and classification and regression trees (C&RT) models. These machine learning processes are used to determine diabetes risk factors, identify patients with diabetes, and automate screening tests that assess blood glucose variability. Additionally, appropriate algorithms can help identify individuals at high risk of diabetes based on genetic and metabolic factors [18]. To date, many large cohort studies have been conducted, attempting to create appropriate models for predicting the onset of diabetes using known risk factors for the disease [16]. Abbasi et al. utilized statistical models such as Cox proportional hazards model, logistic regression, and Weibull distribution analysis to predict the onset of diabetes in healthy individuals over 5 to 10 years. In this study, the accuracy of predicting newly diagnosed diabetes over 5 to 10 years ranged from 0.74 to 0.94 in the C-index [17]. Zou et al., using the random forest method, demonstrated an accuracy of predicting newly diagnosed diabetes in hospitalized patients at a level of 0.81. Choi et al., using logistic regression, reported an area under the curve (AUC) of 0.78 for developing diabetes within 5 years. In other cohort studies and those using electronic medical records to predict diabetes, AUC values in the range of 0.84 to 0.87 were obtained [16]. Table 2 presents a comparison of some studies using machine learning in predicting diabetes.

Authors	Target of the study	Representative ML model	Prediction accuracy
Zou et al. [25]	New-onset DM	Random forest	Accuracy: 0.8084
Choi et al. [26]	New-onset T2DM within 5 years	Logistic regression	AUC: 0.78
Lai et al. [27]	New-onset T2DM	Gradient boosting	AUC: 0.847
Kopitar et al. [28]	New-onset T2DM by fasting plasma glucose levels	Random forest, Gradient boosting	AUC 0.84–0.85
Zhang et al. [29]	New-onset T2DM	Gradient boosting	AUC: 0.872
Nomura et al. [30]	New-onset DM within 1 year	Gradient boosting	AUC: 0.71
Ravaut et al. [31]	New-onset T2DM within 5 years	Gradient boosting	AUC: 0.8026

Table 2. List of studies evaluating prediction of new-onset diabetes mellitus by machine learning models [16].

1.2.2. Deep learning (DL)

In diabetes diagnosis, models based on deep learning are also utilized. The fundamental difference between machine learning and deep learning lies in the quantity and process of analyzing hidden layers of data [19]. While machine learning models typically consist of an input layer, three hidden layers, and an output layer, algorithms employing deep learning can process even hundreds of hidden layers [19, 20]. Moreover, deep learning algorithms use the output data obtained from one layer as the input data for the next layer [20]. Deep learning techniques have found application in diabetes diagnosis by analyzing relevant input data obtained during non-invasive body measurements [19, 21].

1.2.3. Fuzzy Cognitive Maps (FCM)

Fuzzy Cognitive Maps (FCM) are artificial intelligence algorithms that, by analyzing patient data, can be helpful in making medical decisions. FCMs utilize patient information such as medical history, test results, and symptoms to visually represent the relationships between different variables. They can operate on large datasets, identifying relevant patterns and correlations to assist in disease diagnosis. As FCM modeling techniques continue to evolve, their role in medicine is expected to grow further [22]. In studies conducted by Giles et al., the application of fuzzy cognitive maps was demonstrated in detecting diabetes risk factors [23]. In other research, FCMs were used to develop a diabetes prediction system based on risk factors and disease symptoms. Additionally, a fuzzy cognitive map model was developed for early diabetes detection using socio-demographic and clinical information. The results obtained during the study showed promising model effectiveness, with an accuracy of 95%, sensitivity of 96%, and specificity of 94% [24].

1.3. The application of artificial intelligence in diagnosing diabetes complications.

Diabetes is a chronic condition that, when poorly controlled, can lead to various complications in the body. To prevent these complications, it is important to maintain proper blood sugar levels and undergo appropriate screening tests for early detection. Significant advancements in artificial intelligence in recent years have led to the application of new technology in various fields of medicine, including the early detection of diabetes complications [32]. Suitable AI algorithms and methods have been utilized, among others, in the diagnosis of diabetic retinopathy, diabetic foot, and diabetic nephropathy [7].

1.3.1 Diabetic Retinopathy (DR)

Diabetic Retinopathy (DR) is the most common and specific complication of diabetes and the leading cause of blindness among adults, which is largely preventable. Over the past 20 years, the prevalence of vision loss related to DR has increased to 19%, making it crucial to develop appropriate methods to reduce its occurrence frequency [33]. Current screening studies used in early DR diagnosis require significant time investments to keep pace with the growing number of diabetic patients. Artificial intelligence has been shown to potentially reduce specialists' involvement in detecting DR [34]. In recent years, the application of AI has significantly advanced in diagnosing diabetic retinopathy, with numerous algorithms being developed using publicly available Kaggle data containing 100,000 retinal images obtained during screening studies [7]. It is estimated that utilizing these algorithms for rapid diagnosis during routine examinations in primary care, by specialists, and even in pharmacies could prevent vision loss due to the development of diabetic retinopathy [7]. Current AI-based models are used for screening examinations, where the fundus image is analyzed, and automatic assessment of whether the patient has diabetic retinopathy is made. An example of this technology is the IDx-DR diagnostic system developed by Digital Diagnostics Inc [16]. In 2018, the U.S. Food and Drug Administration (FDA) approved the IDx platform for diagnosing DR due to its high diagnostic efficacy in clinical trials [10, 16]. It was the first autonomous artificial intelligence-based system to receive FDA authorization in the field of medicine [7]. The device utilizes algorithms developed using deep learning (DL) to autonomously diagnose diabetic retinopathy based on retinal images, without requiring specialist confirmation. Subsequently, the system assesses the image and classifies patients who require further examination by an ophthalmologist. If the image is normal, the algorithm recommends a repeat examination in 12 months [7, 10, 16]. In 2020, the FDA approved another diagnostic system for autonomous diabetic retinopathy diagnosis - EyeArt. In clinical trials of various commercial programs, including IDx-DR and EyeArt, the algorithms demonstrated sensitivity and specificity exceeding 90% in detecting DR. However, recent real-world studies have shown poorer results, indicating that the algorithms still need refinement [7].

1.3.2. Diabetic Nephropathy (DN)

Diabetic Nephropathy (DN) is a clinical syndrome characterized by the presence of albuminuria and progressive deterioration of kidney function [7, 35]. Uncontrolled progression of nephropathy can ultimately lead to end-stage renal disease (ESRD), which may necessitate hemodialysis or kidney transplantation [7]. Therefore, it is crucial to detect the disease at an early stage to initiate appropriate treatment and halt further progression of kidney failure [35].

Risk factors for DN have been identified based on clinical data and demographic information on existing comorbidities, including dyslipidemia, hypertension, hyperglycemia, and smoking [7, 35]. Although the use of traditional methods in identifying risk factors may be useful, there is still a need to identify patients with a high risk of developing diabetic nephropathy based on their clinical data [7]. A useful indicator of the degree of diabetic nephropathy advancement is the presence of microalbuminuria. However, since many patients do not regularly undergo screening tests for albumin in the urine, models capable of detecting DN without this result may be valuable [7, 35].

In 2021, studies were conducted on the use of artificial intelligence (AI) to predict the progression of diabetic kidney disease (DKD) and compare this method with traditional clinical models. The KidneyIntelX system, which utilizes machine learning in the analysis of electronic health record (EHR) data and three blood biomarkers (TNFR1, TNFR2, KIM-1), was applied for this purpose. The study showed that KidneyIntelX™ outperforms standard clinical models, including KDIGO guidelines, in terms of predicting DKD progression accuracy [36].

In another study, the ability of AI to diagnose diabetic nephropathy based on immunofluorescence images was evaluated. Kidney biopsies were performed on 855 patients, and a dataset containing six types of immunofluorescence images was created. These images were then analyzed using artificial intelligence, focusing on assessing changes observed within the renal glomeruli. Compared to nephrologists, AI results were slightly better, suggesting that artificial intelligence may be effective in diagnosing DN based on immunofluorescence images [37].

Furthermore, artificial intelligence has also been applied to predict end-stage renal disease (ESRD) in patients with type 2 diabetes and nephropathy. Machine learning models, based on demographic and clinical features, were able to predict ESRD with an AUC of 0.84. To predict the occurrence of end-stage renal failure, the models primarily utilized the urinary albumin-to-creatinine ratio, as well as serum levels of albumin, uric acid, and creatinine [38].

1.3.3. Diabetic Foot Syndrome (DFS)

Diabetic Foot Ulceration (DFU) is one of the most severe complications in individuals with diabetes and often leads to limb amputation. Furthermore, the 5-year mortality rate among patients after amputation exceeds 50%. Hence, swift diagnosis and assessment of amputation risk are crucial to enhance patients' quality of life and reduce mortality rates. Currently employed machine learning algorithms can diagnose and localize diabetic foot ulcers based on images of the feet taken by patients. Relevant applications have been developed to assess whether an image provided by a patient exhibits features of diabetic foot ulcers. This is particularly useful for patients with visual impairment or limited access to specialists. In a retrospective hospital-based study, Stefanopoulos et al. identified risk factors that may lead to the development of diabetic foot ulcers. Using machine learning, they developed an algorithm capable of predicting the development of diabetic foot ulcers with an accuracy of up to 79.8%. In another study, machine learning algorithms (LightGBM and SHAP) were utilized to create a model for assessing the likelihood of amputation above the ankle, below the ankle, or abstaining from amputation. The study involved a total of 618 hospitalized patients, yielding satisfactory results in predicting the need for amputation.

Summary

Artificial intelligence (AI) is becoming an integral part of healthcare, with the potential not only to revolutionize disease diagnosis but also in the approach to comprehensive healthcare. The increasing number of scientific articles conducting research using AI in medicine creates opportunities for this technology to be more frequently and successfully utilized in practice. The ability of artificial intelligence to quickly analyze vast amounts of data allows for early disease detection, contributing to improved treatment outcomes. By using appropriate algorithms based on AI, it is possible to accurately analyze medical images, such as X-rays or magnetic resonance imaging, enabling the identification of even the smallest anomalies that could be overlooked by the human eye. This, in turn, leads to faster diagnosis and the initiation of appropriate treatment. Additionally, through the integration and analysis of patient data, AI can help identify patterns that may predict disease risk and prognosis. This opens the door to personalized treatment approaches, where therapies are tailored to individual patient characteristics, increasing treatment efficacy while minimizing side effects. The introduction of artificial intelligence (AI) into medicine, especially in the context of diabetes, opens up new possibilities in early diagnosis and predicting complications of the disease. Research findings suggest that through the application of machine learning and deep learning, AI can assist in analyzing medical data, identifying risk factors for disease onset, and predicting complications. Developed algorithms based on AI technology can be used to expedite the diagnosis of diabetic retinopathy, nephropathy, and other diabetes complications, which is crucial in preventing further disease progression. Despite certain challenges, such as a lack of trust in automated algorithms or the need to adapt models to different patient populations, it is expected that AI-based methods for predicting and diagnosing diabetes complications will be widely used in the future.

Author's contribution:

Conceptualization: S.Z..; methodology: A.B., P.S,; software: S.Z., M.S.; formal analysis: J.T., M.D., Ł.S., K.Ż., M.T., K.K.; investigation; A.Z., O.K., P.S., A.B.., M.S., J.T., M.D., Ł.S., K.Ż., M.T., K.K.; resources: A.B, O.K., P.S., S.Z., M.S., J.T., M.D., Ł.S., K.Ż., M.T., K.K.; data curation: A.B, O.K., P.S., S.Z., M.S., J.T., M.D., Ł.S., K.Ż., M.T., K.K.; writing - rough preparation: A.B, O.K., P.S., S.Z., M.S., J.T., M.D., Ł.S., K.Ż., M.T., K.K.; writing – review and editing: O.K., P.S., S.Z., M.S., J.T., M.D., Ł.S., K.Ż., M.T., K.K.; visualization: A.B., O.K., P.S.,; supervision: Ł.S., K.Ż., M.T., K.K.,; project administration: S.Z., J.T., P.S.,

Supplementary Materials: They have not been provided.

Funding statement: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest. All authors have read and agreed to the published version of the manuscript.

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