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Artificial intelligence for diabetes: Enhancing prevention, diagnosis, and effective management

Mohamed Khalifa [a,b,c,*], Mona Albadawy [d]

[a] College of Health Sciences, Education Centre of Australia, Sydney, Australia
[b] Australian Institute of Health Innovation, Macquarie University, Sydney, Australia
[c] School of Population Health, La Trobe University, Melbourne, Australia
[d] School of Population Health, University of New South Wales, Sydney, Australia

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ABSTRACT

Introduction: Diabetes, a major cause of premature mortality and complications, affects millions globally, with its prevalence increasing due to lifestyle factors and aging populations. This systematic review explores the role of Artificial Intelligence (AI) in enhancing the prevention, diagnosis, and management of diabetes, highlighting the potential for personalised and proactive healthcare.
Methods: A structured four-step method was used, including extensive literature searches, specific inclusion and exclusion criteria, data extraction from selected studies focusing on AI's role in diabetes, and thorough analysis to identify specific domains and functions where AI contributes significantly.
Results: Through examining 43 experimental studies, AI has been identified as a transformative force across eight key domains in diabetes care: 1) Diabetes Management and Treatment, 2) Diagnostic and Imaging Technologies, 3) Health Monitoring Systems, 4) Developing Predictive Models, 5) Public Health Interventions, 6) Lifestyle and Dietary Management, 7) Enhancing Clinical Decision-Making, and 8) Patient Engagement and Self-Management. Each domain showcases AI's potential to revolutionize care, from personalizing treatment plans and improving diagnostic accuracy to enhancing patient engagement and predictive healthcare.
Discussion: AI's integration into diabetes care offers personalised, efficient, and proactive solutions. It enhances care accuracy, empowers patients, and provides better understanding of diabetes management. However, the successful implementation of AI requires continued research, data security, interdisciplinary collaboration, and a focus on patient-centered solutions. Education for healthcare professionals and regulatory frameworks are also crucial to address challenges like algorithmic bias and ethics.
Conclusion and Recommendations: AI in diabetes care promises improved health outcomes and quality of life through personalised and proactive healthcare. Future efforts should focus on continued investment, ensuring data security, fostering interdisciplinary collaboration, and prioritizing patient-centered solutions. Regular monitoring and evaluation are essential to adjust strategies and understand long-term impacts, ensuring AI's ethical and effective integration into healthcare.

Introduction

Diabetes is a chronic health condition where the body is unable to properly process blood glucose, often due to insufficient insulin production (Type 1) or insulin resistance (Type 2). This leads to hyperglycaemia which can cause a range of health issues [1]. Poorly controlled blood glucose levels can lead to acute emergencies like diabetic ketoacidosis and hyperglycaemic hyperosmolar state [2]. Likewise, several serious long-term complications can be caused by diabetes, especially if it is not managed effectively. These include cardiovascular diseases, nerve damage, kidney failure, vision problems, and a higher risk of infection [3]. Moreover, diabetes is one of the major causes of premature mortality [4]. As a major global health concern, diabetes affects millions due to factors like obesity, inactivity, and aging. The World Health Organization reports 422 million cases in 2014, a fourfold increase since 1980, leading to 2 million deaths in 2019. This epidemic challenges healthcare systems, underlining the need for effective prevention and management [5,6].

* Corresponding author at: College of Health Sciences, Education Center of Australian, Level 6, 1/3 Fitzwilliam St, Parramatta, NSW 2150, Australia.
E-mail address: mohamed.khalifa@chs.edu.au (M. Khalifa).

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The development of newer technologies in healthcare has opened up novel opportunities for managing diabetes more effectively. This is particularly important given the disease's complexity and the need for continual monitoring and adjustment of treatment plans. These technologies range from advanced glucose monitoring devices to software applications that assist in tracking and analysing patient data, contributing significantly to more personalized and effective diabetes care [7].

In this domain, Artificial Intelligence (AI) is transforming diabetes care, providing advancements in early risk assessment, diagnosis, and personalized management. AI analyses large datasets to predict risks, interprets test results accurately, and customizes treatment plans, enhancing patient care and outcomes [8]. By incorporating AI into the healthcare system, there is potential for a significant reduction in the burden of diabetes care, shifting towards a more proactive and personalized approach [9]. This systematic review explores the AI's impact on improving prevention, diagnosis, and management of diabetes, assessing its readiness for integration into healthcare, identifying research gaps, and guiding future developments.

Methods

Conducting this systematic review followed a four-step structured method. First, an extensive search was conducted through databases such as PubMed, Embase, and Google Scholar, focusing on studies published in English since 2019, using search keywords such as "artificial intelligence", "machine learning", and "diabetes mellitus". This search aimed at gathering experimental studies examining the use of AI in diabetes prevention, diagnosis, or management. Based on specific criteria, studies were included if they investigated the role of AI in enhancing the prevention, diagnosis, prognosis, monitoring, or management of diabetes. Studies were excluded if they were irrelevant or methodologically unclear. Essential data were extracted, focusing on the objectives of each study, their used AI techniques, main findings, and conclusions. The data was then collected and synthesised to highlight critical areas where AI significantly contributed to the prevention, diagnosis, or management of diabetes. The last step included a thorough analysis of the collected information. This analysis aimed at clarifying the specific domains and roles of AI in enhancing diabetes management, developing these into specific domains and functions.

Results

The search for published papers revealed 304 studies. Only 202 unique studies were identified after duplicates were removed. Applying inclusion and exclusion criteria, 114 studies were excluded after screening the titles and another 19 studies were excluded after screening the abstracts. After full-text examination, only 43 studies, out of 88, were included. Fig. 1 shows the study selection and inclusion processes.

Using qualitative analysis, this review identified eight domains where AI has the potential to revolutionize the landscape of diabetes management, supporting more accurate, personalised, and effective diabetes management and treatment outcomes. In the domain of Diabetes Management and Treatment, AI algorithms stand at the forefront, personalizing management strategies by predicting blood glucose levels and optimizing insulin dosages. These sophisticated algorithms continuously analyze patient data, leading to more tailored and effective

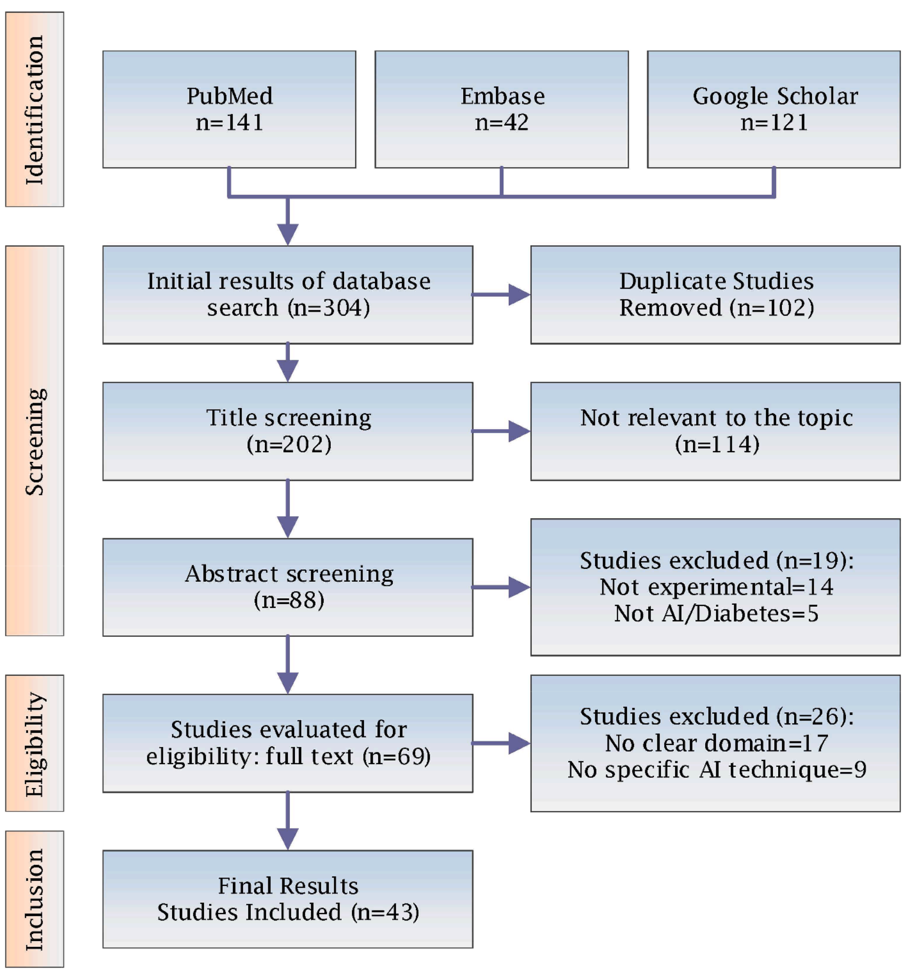

Fig. 1. PRISMA flowchart of study selection and inclusion process.

treatment plans [10]. Among the 43 studies included in this review, 19 studies discussed the role of AI in this domain. Moving to the domain of Diagnostic and Imaging Technologies, AI significantly elevates the precision and efficiency of diagnostic tools. Its application in medical imaging, such as MRI scans, plays a crucial role in the early detection and ongoing monitoring of diabetes-related complications. This technological advancement ensures that subtle changes in patients' health are identified swiftly, facilitating prompt intervention [11]. This domain was discussed by eight studies. In the sphere of Health Monitoring Systems, the integration of AI with devices like continuous glucose monitors revolutionises real-time blood glucose tracking. These AI-enhanced systems not only monitor but also predict fluctuations in glucose levels, thus alerting patients and caregivers to potential health risks, and significantly contributing to proactive diabetes management [12]. This domain was discussed by three studies. AI's contribution to Developing Predictive Models is equally noteworthy. Here, AI is instrumental in forecasting the onset or progression of diabetes and its associated risks. By analysing extensive health data, these models can pinpoint risk factors and predict patient responses to various treatments, paving the way for more personalised and preventive healthcare approaches [13]. This domain was discussed by 33 studies.

The role of AI extends into Public Health Interventions as well, where it assists in creating tools for risk assessment of conditions like stroke in diabetic patients. These AI-driven tools are vital in formulating preventive strategies, thus playing a key role in public health initiatives aimed at mitigating the impact of diabetes-related complications [8]. This domain was discussed by eight studies. Furthermore, in the area of Lifestyle and Dietary Management, AI's application is revolutionizing how dietary and lifestyle advice is imparted to patients with diabetes. By customizing recommendations based on individual health profiles and preferences, AI aids in making lifestyle interventions more effective and patient-centric [14]. This domain was discussed by 15 studies. In enhancing Clinical Decision-Making, AI acts as a powerful ally for healthcare professionals. It aids in sifting through patient data to suggest the most effective treatment options, thereby improving the overall quality of care and ensuring that clinical decisions are both accurate and efficient [15]. This domain was discussed by 22 studies. Lastly, in the domain of Patient Engagement and Self-Management, AI-driven tools and platforms actively engage patients in their own care. These tools not only provide personalised management advice but also track adherence to treatment plans, empowering patients to manage their condition effectively, thus leading to improved health outcomes [16]. This domain was discussed by 20 studies. Overall, the integration of AI across these domains signifies a transformative shift in how diabetes is managed and treated, offering a more nuanced, data-driven approach that holds great promise for patient care and outcomes [17]. Fig. 2, and the table in the Appendix, show the eight domains where AI supports diabetes management. Table 1 shows the mapping of the 43 studies to the identified eight domains. Accordingly, Fig. 3 shows the potential contributions of the AI to diabetes domains. Table 2 show the detailed extracted information from the 43 studies, regarding their objectives, population, sample size, interventions, outcome measures, ai models, findings, and conclusions.

Discussion

Diabetes Management and Treatment encapsulates a groundbreaking approach in healthcare, harnessing AI to revolutionize the management of diabetes. The recent studies in this domain demonstrate a diverse range of applications and substantial advancements. AI algorithms are now capable of personalizing diabetes management by accurately predicting blood glucose levels, optimizing insulin dosages, and customizing treatment plans based on individual patient data [10]. Key findings from these studies highlight the multifaceted nature of AI applications in diabetes care. For instance, Liu et al., 2020, and Khorraminezhad et al., 2021, illustrated the significant role of lifestyle factors, such as exercise and diet, in modulating glucose homeostasis, where AI algorithms help in understanding and predicting these complex interactions [18,49]. Rein et al., 2022, and Joshi et al., 2023, further underscored the effectiveness of personalised nutrition plans developed through AI in improving glycaemic control and metabolic health [21,36]. Innovations in machine learning, as shown in the works of Zhang et al., 2022, and Oikonomou et al., 2022, have enabled the prediction of adherence risks and personalization of treatment effects, respectively. This demonstrates AI's capability to tailor treatment to individual patient profiles, leading to more effective management of diabetes [24,41]. Additionally, the integration of AI into medical devices and digital platforms, as seen in the studies by Faruqui et al., 2019, Avari et al., 2021, and Lee et al., 2023, offers a new dimension of real-time, data-driven management. These platforms aid in continuous monitoring and adjusting treatment plans, significantly improving patient outcomes [28,32,58].

AI in Diagnostic and Imaging Technologies primarily explores how artificial intelligence enhances the accuracy and efficiency of diagnostic

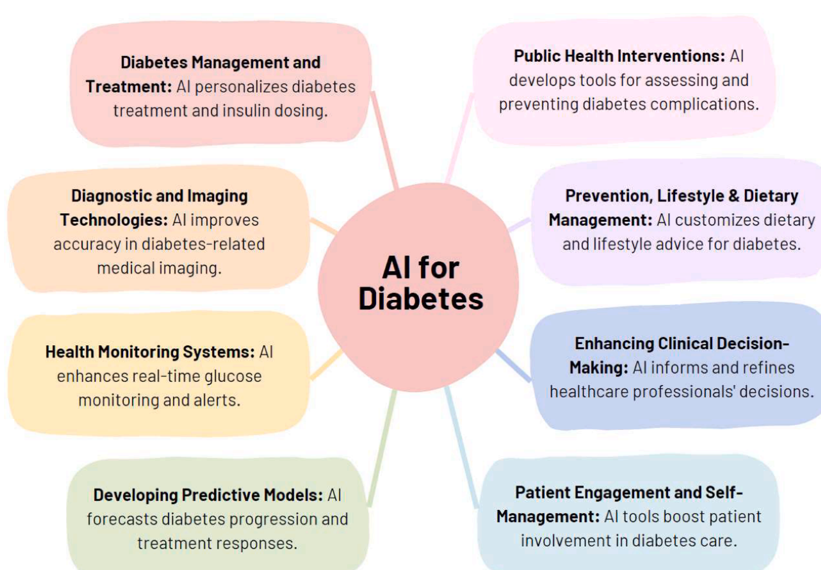

Fig. 2. AI Enhances Eight Domains of Diabetes Management.

Table 1
Mapping the 43 Studies to the Eight AI Domains.

SN	Study	Diabetes Management and Treatment	Diagnostic and Imaging Technologies	Health Monitoring Systems	Developing Predictive Models	Public Health Interventions	Lifestyle and Dietary Management	Enhancing Clinical Decision-Making	Patient Engagement and Self-Management
1	Liu et al., 2020 [18]	✓			✓	✓		✓	✓
2	Wei et al., 2022 [19]				✓	✓			
3	Seethaler et al., 2022 [20]				✓		✓		
4	Rein et al., 2022 [21]	✓			✓			✓	✓
5	Popp et al., 2022 [22]				✓		✓		
6	Han et al., 2022 [23]		✓						
7	Zhang et al., 2022 [24]	✓		✓	✓			✓	✓
8	Zou et al., 2024 [25]				✓	✓		✓	
9	Varga et al., 2021 [26]				✓			✓	
10	Roberts et al., 2020 [27]		✓						
11	Faruqui et al., 2019 [28]	✓		✓	✓			✓	
12	Sampedro et al., 2020 [29]				✓	✓		✓	
13	Oikonomou et al., 2022 [30]				✓	✓		✓	
14	Hong et al., 2023 [31]				✓				
15	Avari et al., 2021 [32]	✓			✓			✓	✓
16	Wang et al., 2023 [33]				✓	✓		✓	
17	Saux et al., 2023 [34]				✓		✓	✓	✓
18	Nimri et al., 2020 [35]	✓			✓			✓	✓
19	Joshi et al., 2023 [36]	✓			✓		✓	✓	✓
20	Moyen et al., 2022 [37]						✓		
21	Popp et al., 2019 [38]				✓		✓	✓	✓
22	Du et al., 2022 [39]		✓						
23	Chauhan et al., 2021 [40]	✓			✓		✓		✓
24	Oikonomou et al., 2022 [41]	✓			✓			✓	✓
25	Habes et al., 2023 [42]		✓		✓				
26	Ashrafi et al., 2021 [43]				✓		✓		✓
27	Khanji et al., 2019 [44]				✓	✓			
28	Reddy et al., 2019 [45]	✓		✓	✓			✓	✓
29	Sarici et al., 2023 [46]		✓						
30	Nayak et al., 2023 [47]	✓							✓
31	Abraham et al., 2021 [48]		✓					✓	
32	Khorraminezhad et al., 2021 [49]	✓			✓		✓		✓
33	Unsworth et al., 2023 [50]	✓			✓			✓	✓
34	Gastaldelli et al., 2021 [51]				✓	✓	✓		
35	Sun et al., 2023 [52]	✓			✓		✓		✓

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Table 1 (*continued*)

SN	Study	Diabetes Management and Treatment	Diagnostic and Imaging Technologies	Health Monitoring Systems	Developing Predictive Models	Public Health Interventions	Lifestyle and Dietary Management	Enhancing Clinical Decision-Making	Patient Engagement and Self-Management
36	Park et al., 2020 [53]	✓			✓		✓	✓	✓
37	Wang et al., 2022 [54]		✓						
38	Nunez Lopez et al., 2019 [55]	✓			✓				
39	Alfonsi et al., 2020 [56]	✓			✓		✓	✓	✓
40	Ben-Yacov et al., 2023 [57]						✓		
41	Lee et al., 2023 [58]	✓			✓		✓	✓	✓
42	Benhamou et al., 2019 [59]	✓			✓			✓	✓
43	Zhao et al., 2022 [60]		✓						
Studies discussing each domain		19	8	3	33	8	15	22	20

✓ = Discussed domains in the 74 studies.

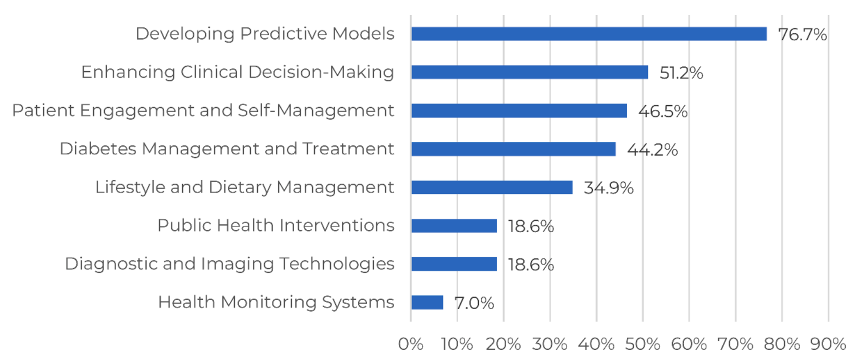

Fig. 3. AI Contribution to Diabetes Management, Based on the 43 Studies.

tools, specifically in medical imaging like MRI, for identifying and monitoring diabetes-related complications [11]. Studies like those by Han et al., 2022, and Roberts et al., 2020, demonstrate AI's capability in improving the diagnostic accuracy of diabetic macular edema (DME) and automated segmentation of fluid in DME, respectively. This not only facilitates a deeper understanding of treatment responses but also supports personalised healthcare strategies [23,27]. Further, Du et al., 2022, and Habes et al., 2023, highlight AI's role in functional Magnetic Resonance Imaging (fMRI) and detecting early signs of cognitive decline in diabetic individuals. These advancements show AI's potential in early intervention and reducing diagnostic errors [39,42]. Similarly, Sarici et al., 2023, and Abraham et al., 2021, focus on ultrawide-field angiographic parameters and identifying biomarkers for therapy response in DME, indicating AI's contribution to enhancing treatment efficacy [46,48]. Additionally, studies by Wang et al., 2022, and Zhao et al., 2022, illustrate the use of AI in evaluating treatment for diabetic foot and monitoring renal function in diabetic kidney disease. These findings suggest that AI not only augments the precision of existing diagnostic methods but also opens new avenues for continuous monitoring and treatment optimization, marking a significant shift towards more tailored and effective diabetes management [54,60].

AI in Health Monitoring Systems focuses on integrating artificial intelligence with health monitoring devices to enhance real-time tracking and management of blood glucose levels, particularly vital for diabetes care. The advancements are illustrated through studies that demonstrate AI's potential in creating a more responsive and personalised healthcare environment [15,61]. For example, Zhang et al., 2022, showcased the use of machine learning to predict self-management adherence in Type 1 Diabetes, indicating how AI can identify individual barriers and tailor interventions accordingly. This personalization is crucial for effective diabetes management, as it accounts for the unique challenges individuals face, enhancing their ability to manage their condition proactively [24]. Likewise, Faruqui et al., 2019, advanced this domain by developing a deep learning model that utilises mobile health data to forecast blood glucose levels dynamically. Their work represents a significant stride in predictive health monitoring, allowing patients with Type 2 Diabetes to anticipate and adjust their lifestyle and treatment options in advance, thereby preventing potential complications [28]. Lastly, Reddy et al., 2019, tackled exercise-induced hypoglycaemia, a critical concern for individuals with Type 1 Diabetes. By creating algorithms to predict hypoglycemics events during aerobic exercise, they provide a tool for safer physical activity, contributing to overall better diabetes management and quality of life [45]. Collectively, these studies highlight the transformative role of AI in health monitoring systems, offering more accurate, real-time insights and predictions that empower individuals with diabetes to manage their health more effectively and safely. AI's ability to analyze vast data, predict health issues, and provide personalized monitoring enhances diagnostic precision, integrates diverse health data, and strengthens remote monitoring. This evolution leads to proactive, efficient healthcare, with AI's continuous learning significantly enhancing patient care and system efficiency [62].

AI in Developing Predictive Models marks a transformative era in healthcare, particularly in diabetes management. This domain explores

Table 2
Objectives, Populations, Sample Size, Interventions, Outcome Measures, AI Models Used, Findings, and Conclusions of the 43 Included Studies.

SN	Author & Year	Title	Objective / Purpose	Population / Participants	Sample Size	Intervention / Exposure	Outcome Measures	AI/ML Model Used	Findings and Conclusions
1	Liu et al., 2020 [18]	Gut Microbiome Fermentation Determines the Efficacy of Exercise for Diabetes Prevention	To examine exercise-induced alterations in gut microbiota and their impact on glucose homeostasis	Men with prediabetes	39	Exercise	Glucose homeostasis, insulin sensitivity	Machine-learning algorithm	Exercise-induced changes in gut microbiota correlated with improvements in glucose homeostasis and insulin sensitivity in prediabetes. Responders exhibited enhanced capacity for short-chain fatty acids biosynthesis.
2	Wei et al., 2022 [19]	Environmental Chemical Exposure Dynamics and Machine Learning-Based Prediction of Diabetes Mellitus	To assess the utility of environmental chemical exposure in predicting diabetes mellitus	General population	8501	Environmental chemical exposure	Diabetes prediction	Random forest, LASSO regression	Environmental chemical exposure dynamics and machine learning predicted diabetes mellitus with notable accuracy, emphasizing the predictive value of widespread environmental chemicals for complex diseases.
3	Seethaler et al., 2022 [20]	Short-Chain Fatty Acids are Key Mediators of the Favorable Effects of the Mediterranean Diet on Intestinal Barrier Integrity: Data from the Randomized Controlled LIBRE Trial	To determine if the Mediterranean diet, via SCFAs, improves intestinal barrier integrity	Women with intestinal barrier impairment	260	Mediterranean diet	SCFA concentrations, intestinal permeability	Machine-learning algorithm	Mediterranean diet, via induction of short-chain fatty acids, improved intestinal barrier integrity.
4	Rein et al., 2022 [21]	Effects of Personalized Diets by Prediction of Glycemic Responses on Glycemic Control and Metabolic Health in Newly Diagnosed T2DM: A Randomized Dietary Intervention Pilot Trial	To evaluate the effects of a personalized postprandial-targeting diet on glycemic control in T2DM	Adults with newly diagnosed T2DM	23	Personalized postprandial-targeting diet	Glycemic measures, metabolic health parameters	Machine learning algorithm	Personalized diets based on prediction of glycemic responses showed improved glycemic control in individuals with newly diagnosed type 2 diabetes compared to a Mediterranean-style diet.
5	Popp et al., 2022 [22]	Effect of a Personalized Diet to Reduce Postprandial Glycemic Response vs a Low-Fat Diet on Weight Loss in Adults With Abnormal Glucose Metabolism and Obesity: A Randomized Clinical Trial	To compare the effectiveness of a personalized diet vs a low-fat diet for weight loss in adults with abnormal glucose metabolism and obesity	Adults with abnormal glucose metabolism and obesity	204	Personalized diet vs low-fat diet	Weight loss, body composition	Machine learning algorithm	A personalized diet targeting reduction in postprandial glycemic response did not result in greater weight loss compared with a low-fat diet at 6 months.
6	Han et al., 2022 [23]	Deep Learning Algorithm-Based MRI Image in the Diagnosis of Diabetic Macular Edema	To evaluate the effectiveness of a deep learning algorithm in diagnosing Diabetic Macular Edema (DME) using MRI images	Patients with DME	96	Deep learning 3D convolutional neural network (3D-CNN) algorithm for MRI images	MRI image quality, diagnostic accuracy	3D-CNN	Deep learning algorithm-based MRI significantly improved diagnostic accuracy for diabetic macular edema.
7	Zhang et al., 2022 [24]	Using Momentary Assessment and Machine Learning to Identify Barriers to Self-Management in Type 1 Diabetes: Observational Study	To develop a machine learning algorithm to predict the risk of missed self-management in young adults with Type 1 Diabetes	Adolescents with Type 1 Diabetes	Not specified	Momentary assessment data, blood glucose data	Self-management behaviors	Machine learning-based filtering architecture	Machine learning combined with momentary assessment data showed promise in predicting self-management adherence risks in type 1 diabetes.
8	Zou et al., 2024 [25]	Differential Effect of Interventions in Patients with Prediabetes Stratified by a Machine Learning-Based	To investigate the effects of stratifying prediabetes patients by diabetes progression	Patients with prediabetes	2558	Lifestyle and/or pioglitazone intervention	Prediabetes reversal, diabetes progression	Machine learning model (XGBoost)	Stratifying prediabetes patients by diabetes progression risks using a machine learning-based

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Table 2 (*continued*)

SN	Author & Year	Title	Objective / Purpose	Population / Participants	Sample Size	Intervention / Exposure	Outcome Measures	AI/ML Model Used	Findings and Conclusions
		Diabetes Progression Prediction Model	risks on their response to interventions						model impacted their responses to various interventions.
9	Varga et al., 2021 [26]	Predictive Utilities of Lipid Traits, Lipoprotein Subfractions and Other Risk Factors for Incident Diabetes: A Machine Learning Approach in the Diabetes Prevention Program	To compare the discriminative utility of various biomarkers for diabetes prediction	Individuals with pre-diabetes	2590	Not applicable	Incident diabetes	Machine learning algorithms	NMR-derived biomarkers did not augment discrimination of diabetes risk beyond traditional risk factors. Machine learning did not provide meaningful improvement over logistic regression.
10	Roberts et al., 2020 [27]	Quantification of Fluid Resolution and Visual Acuity Gain in Patients With Diabetic Macular Edema Using Deep Learning: A Post Hoc Analysis of a Randomized Clinical Trial	To examine volumetric changes of intraretinal and subretinal fluid in DME during anti-VEGF treatment using deep learning	Patients with DME	570	Anti-VEGF treatment	Fluid volume changes, visual acuity	Deep learning algorithms	Automated segmentation of fluid in diabetic macular edema revealed that the presence of subretinal fluid was associated with lower baseline visual acuity but with good response to therapy.
11	Faruqui et al., 2019 [28]	Development of a Deep Learning Model for Dynamic Forecasting of Blood Glucose Level for Type 2 Diabetes Mellitus: Secondary Analysis of a Randomized Controlled Trial	To forecast daily glucose levels in T2DM based on lifestyle data	Patients with T2DM	10	Mobile health lifestyle data	Blood glucose level prediction	Long short-term memory-based RNNs	A deep learning model based on mobile health data accurately predicted future glucose levels in type 2 diabetes patients.
12	Sampedro et al., 2020 [29]	Machine Learning to Predict Stent Restenosis Based on Daily Demographic, Clinical, and Angiographic Characteristics	To use ML to predict stent restenosis using daily practice data	Patients with stent implantation	263	Not applicable	Stent restenosis prediction	Various ML classifiers	A machine learning model outperformed existing scores in predicting stent restenosis in patients post-percutaneous coronary intervention.
13	oikonomou et al., 2022 [30]	individualizing intensive systolic blood pressure reduction in hypertension using computational trial phenomaps and machine learning: a post-hoc analysis of randomised clinical trials	To define personalized cardiovascular benefits of intensive systolic blood pressure control	Patients with hypertension	Not specified	Intensive systolic blood pressure control	Cardiovascular event prediction	XGBoost algorithm	Machine learning applied to clinical trials data successfully individualized the cardiovascular benefit of intensive control of systolic blood pressure in patients with or without type 2 diabetes.
14	Hong et al., 2023 [31]	Predictive Model for Urosepsis in Patients with Upper Urinary Tract Calculi Based on Ultrasonography and Urinalysis Using Artificial Intelligence Learning	To construct a predictive model for urosepsis risk in patients with upper urinary tract calculi	Patients with upper urinary tract calculi	1716	Ultrasonography and urinalysis data	Urosepsis prediction	Artificial Neural Network (ANN)	An artificial intelligence learning-based model successfully predicted the risk of urosepsis in patients with upper urinary tract calculi.
15	Avari et al., 2021 [32]	Safety and Feasibility of the PEPPER Adaptive Bolus Advisor and Safety System: A Randomized Control Study	To evaluate the safety and efficacy of the PEPPER system for personalized bolus advice in type 1 diabetes	People with type 1 diabetes	54	PEPPER system for bolus advice	Glycemic outcomes, safety	Case-based reasoning AI	The PEPPER Adaptive Bolus Advisor and Safety System was safe but did not change glycemic outcomes compared to control in type 1 diabetes.
16	Wang et al., 2023 [33]	Development and Validation of a Prediction Model Based on Machine Learning Algorithms for Predicting the Risk of Heart Failure in Middle-Aged and Older US People with Prediabetes or Diabetes	To develop and validate an ML-based prediction model for heart failure risk in patients with prediabetes or diabetes	Middle-aged and older individuals with prediabetes or diabetes	3527	Not applicable	Heart failure risk prediction	Various ML algorithms, including random forest	A machine learning model effectively predicted the risk of heart failure in US individuals with prediabetes or diabetes.

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Table 2 (*continued*)

SN	Author & Year	Title	Objective / Purpose	Population / Participants	Sample Size	Intervention / Exposure	Outcome Measures	AI/ML Model Used	Findings and Conclusions
17	Saux et al., 2023 [34]	Development and Validation of an Interpretable Machine Learning-Based Calculator for Predicting 5-Year Weight Trajectories After Bariatric Surgery: A Multinational Retrospective Cohort SOPHIA Study	To develop a model for predicting individual 5-year weight loss trajectories after bariatric surgery	Post-bariatric surgery patients	10,231	Bariatric surgery (various types)	5-year weight loss trajectories	LASSO, CART algorithms	Machine learning-based calculator effectively predicted 5-year weight trajectories after bariatric surgery in a multinational cohort.
18	Nimri et al., 2020 [35]	Insulin Dose Optimization Using an Automated Artificial Intelligence-Based Decision Support System in Youths with Type 1 Diabetes	To compare insulin dose adjustments by AI-DSS and physicians	Youths with Type 1 Diabetes	108	AI-DSS for insulin adjustment	Time within target glucose range	AI-based DSS	Automated AI-based decision support system for insulin dose optimization was effective and safe in managing type 1 diabetes in youths.
19	Joshi et al., 2023 [36]	Digital Twin-Enabled Personalized Nutrition Improves Metabolic Dysfunction-Associated Fatty Liver Disease in Type 2 Diabetes: Results of a 1-Year Randomized Controlled Study	To assess the effect of DT-enabled personalized nutrition on T2D and MAFLD	Patients with T2D	319	Personalized meal plans by AI	Change in HbA1c, liver fat scores	Digital Twin technology	Digital twin-enabled personalized nutrition significantly improved metabolic dysfunction-associated fatty liver disease in patients with type 2 diabetes.
20	Moyen et al., 2022 [37]	Relative Validation of an Artificial Intelligence-Enhanced, Image-Assisted Mobile App for Dietary Assessment in Adults: Randomized Crossover Study	To evaluate the validity of Keenoa app against ASA24 for dietary assessment	Adults, including those with diabetes	136	Keenoa app for dietary tracking	Reported energy and nutrient intakes	AI-enhanced app	The Keenoa app showed moderate to strong validity against ASA24 for energy, macronutrient, and most micronutrient intakes in healthy adults and those with diabetes.
21	Popp et al., 2019 [38]	The Rationale and Design of the Personal Diet Study, a Randomized Clinical Trial Evaluating a Personalized Approach to Weight Loss in Individuals with Pre-Diabetes and Early-Stage Type 2 Diabetes	Evaluate two dietary interventions for weight loss in T2D	Individuals with prediabetes and T2D	Not specified	Low-fat diet and personalized diet using ML algorithm	Changes in body weight, composition, and energy expenditure	Machine learning for dietary response	The Personal Diet Study aimed to evaluate two dietary interventions targeting weight loss in people with prediabetes and T2D: a low-fat diet, and a personalized diet using a machine-learning algorithm.
22	Du et al., 2022 [39]	Evaluation of Functional Magnetic Resonance Imaging under Artificial Intelligence Algorithm on Plan-Do-Check-Action Home Nursing for Patients with Diabetic Nephropathy	Evaluate the effect of fMRI under AI on home nursing for diabetic nephropathy	Patients with diabetic nephropathy	64	PDCA home nursing	Efficacy, nursing satisfaction, quality of life	Fuzzy C-means clustering algorithm	Improved FCM algorithm detected activation regions in fMRI images more effectively, aiding in diagnosis and reducing error and misdiagnosis in patients with diabetic nephropathy.
23	Chauhan et al., 2021 [40]	An Artificial-Intelligence-Discovered Functional Ingredient, NRT_N0G5IJ, Derived from Pisum sativum, Decreases HbA1c in a Prediabetic Population	Investigate a functional ingredient for glucose regulation in prediabetes	Individuals with elevated HbA1c	Not specified	NRT_N0G5IJ supplementation	Reduction in glycated hemoglobin levels	AI for ingredient discovery	Using AI, a functional ingredient from peas was discovered and shown to reduce HbA1c in prediabetic individuals.
24	Oikonomou et al., 2022 [41]	Phenomapping-Derived Tool to Individualize the Effect of Canagliflozin on Cardiovascular Risk in Type 2 Diabetes	Develop an ML-based tool for personalized ASCVD effects of canagliflozin	Patients with type 2 diabetes	4327	Canagliflozin	Major adverse cardiovascular events	Extreme gradient boosting algorithm	Developed a machine learning-based decision support tool to individualize the atherosclerotic cardiovascular disease (ASCVD) benefit of canagliflozin in type 2 diabetes.

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Table 2 (*continued*)

SN	Author & Year	Title	Objective / Purpose	Population / Participants	Sample Size	Intervention / Exposure	Outcome Measures	AI/ML Model Used	Findings and Conclusions
25	Habes et al., 2023 [42]	Patterns of Regional Brain Atrophy and Brain Aging in Middle- and Older-Aged Adults With Type 1 Diabetes	Evaluate brain age and AD-like atrophy in T1D	Adults with type 1 diabetes	416	Not applicable	Brain age, atrophy, cognitive performance	Machine learning indices for brain age	Study suggests an increase in brain aging among individuals with Type 1 Diabetes without early signs of Alzheimer's-related neurodegeneration.
26	Ashrafi et al., 2021 [43]	Computational modeling of self-reported dietary carbohydrate intake on glucose concentrations in patients undergoing Roux-en-Y gastric bypass versus one-anastomosis gastric bypass	Model postprandial glucose concentrations in patients post-bariatric surgery	Morbidly obese patients undergoing surgery	17	RYGB or OAGB surgery	Glucose concentrations, carbohydrate intakes	Machine learning model	Investigated the use of machine learning for modeling postprandial glucose concentrations in obese patients undergoing gastric bypass surgeries.
27	Khanji et al., 2019 [44]	Lasso Regression for the Prediction of Intermediate Outcomes Related to Cardiovascular Disease Prevention Using the TRANSIT Quality Indicators	Assess prediction models for therapeutic targets in cardiovascular disease	Patients with hypertension, dyslipidemia, diabetes	870	Not applicable	Achievement of therapeutic targets	Lasso regression, machine learning	Identified a set of 5 process indicators with good predictive validity for intermediate outcomes related to cardiovascular disease prevention.
28	Reddy et al., 2019 [45]	Prediction of Hypoglycemia During Aerobic Exercise in Adults With Type 1 Diabetes	Develop algorithms to predict exercise-related hypoglycemia in T1D	Adults with type 1 diabetes	43	Not applicable	Prediction of hypoglycemia during exercise	Decision tree and random forest models	Developed and evaluated two algorithms to predict hypoglycemia during exercise in adults with Type 1 Diabetes.
29	Sarici et al., 2023 [46]	Longitudinal Quantitative Ultrawide-field Fluorescein Angiography Dynamics in the RUBY Diabetic Macular Edema Study	Evaluate quantitative UWFA parameters in DME treatment	Patients with diabetic macular edema	44	Aflibercept injection or combined IAI/ nesvacumab	Changes in UWFA parameters, OCT metrics	Machine learning-enabled feature extraction	Quantitative ultrawide-field angiographic parameters significantly improved in eyes treated with IAI with or without nesvacumab for diabetic macular edema.
30	Nayak et al., 2023 [47]	Use of Voice-Based Conversational Artificial Intelligence for Basal Insulin Prescription Management Among Patients With Type 2 Diabetes: A Randomized Clinical Trial	Examine the efficacy of a voice-based AI application in insulin titration	Adults with type 2 diabetes	32	Voice-based AI application for insulin management	Optimal insulin dose, adherence, glycemic control	Conversational AI application	A voice-based conversational AI application significantly improved time to optimal insulin dose, insulin adherence, glycemic control, and diabetes-related emotional distress compared to standard care.
31	Abraham et al., 2021 [48]	Aqueous Cytokine Expression and Higher Order OCT Biomarkers: Assessment of the Anatomic-Biologic Bridge in the IMAGINE DME Study	Identify biomarkers predicting response to anti-VEGF in DME	Patients with diabetic macular edema	24	Anti-VEGF therapy	OCT imaging biomarkers, cytokine expression	Optical coherence tomography machine-learning augmented segmentation platform	Identified biomarkers for predicting response to anti-vascular endothelial growth factor therapy in diabetic macular edema, linking cytokine expression and OCT phenotype.
32	Khorraminezhad et al., 2021 [49]	Dairy product intake modifies gut microbiota composition among hyperinsulinemic individuals	Investigate the effect of high dairy intake on gut microbiota and insulin resistance	Hyperinsulinemic adults	10	High dairy intake	Gut microbiota composition, insulin resistance	Machine learning analyses	High dairy intake modifies gut microbiota composition and correlates negatively with insulin resistance in hyperinsulinemic individuals.
33	Unsworth et al., 2023 [50]	Safety and Efficacy of an Adaptive Bolus Calculator for Type 1 Diabetes: A Randomized Controlled Crossover Study	Assess the ABC4D system for insulin bolus doses in T1D	Adults with type 1 diabetes	37	ABC4D system for insulin dosing	Time in range, glycemic control	Case-based reasoning AI technique	The Advanced Bolus Calculator for Type 1 Diabetes (ABC4D) is safe for adapting insulin bolus doses and provided the same level of glycemic control as the nonadaptive bolus calculator.
34	Gastaldelli et al., 2021 [51]	PPAR-γ-induced changes in visceral fat and adiponectin levels are associated with	Understand the impact of PPAR-γ agonists on steatohepatitis in NASH	Patients with NASH	55	PPAR-γ agonists (pioglitazone)	Hepatic/visceral fat, adiponectin levels	Machine learning techniques	Reduction in visceral fat and improved fat distribution, combined with an increase in

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Table 2 (*continued*)

SN	Author & Year	Title	Objective / Purpose	Population / Participants	Sample Size	Intervention / Exposure	Outcome Measures	AI/ML Model Used	Findings and Conclusions
		improvement of steatohepatitis in patients with NASH							adiponectin, mediate the histological benefits of PPAR-γ action in patients with NASH.
35	Sun et al., 2023 [52]	Effects of Endurance Exercise and Vitamin D Supplementation on Insulin Resistance and Plasma Lipidome in Middle-Aged Adults with Type 2 Diabetes	Investigate the impact of exercise and vitamin D on insulin resistance in T2D	Middle-aged adults with type 2 diabetes	61	Endurance exercise and vitamin D supplementation	Insulin resistance, plasma lipidome	Machine learning for personalized response prediction	The 12-week exercise intervention with or without vitamin D supplementation had a substantial impact on the plasma lipidome related to glycemic control in middle-aged adults with type 2 diabetes.
36	Park et al., 2020 [53]	Validation of the effectiveness of a digital integrated healthcare platform utilizing an AI-based dietary management solution and a real-time continuous glucose monitoring system for diabetes management: a randomized controlled trial	Evaluate the effectiveness of a digital healthcare platform with AI-based dietary management for diabetes	Adults with type 2 diabetes	294	Digital healthcare platform with AI-based dietary management	Change in HbA1c, weight loss	AI-based dietary management solution	Investigated the efficacy of a digital integrated healthcare platform using an AI-based dietary management solution and a continuous glucose monitoring system in patients with type 2 diabetes.
37	Wang et al., 2022 [54]	Magnetic Resonance Imaging Data Features to Evaluate the Efficacy of Compound Skin Graft for Diabetic Foot	Analyze the role of MRI data characteristics in evaluating compound skin graft treatment for diabetic foot	Patients with diabetic foot	78	Compound skin graft treatment	Healing time, recurrence rate, scar score	KNL-Means filtering algorithm for MRI	MRI image data characteristics based on deep learning algorithm can provide auxiliary reference information for the efficacy evaluation of compound skin transplantation for diabetic foot.
38	Nunez Lopez et al., 2019 [55]	Predicting and understanding the response to short-term intensive insulin therapy in people with early type 2 diabetes	Predict and understand the response to intensive insulin therapy in early type 2 diabetes	Adults with early type 2 diabetes	24	Short-term intensive insulin therapy	Beta-cell function, postprandial glucose responses	Random survival forest and Cox models	Identified potential responders to intensive insulin therapy in early type 2 diabetes and provided insight into the pathophysiologic determinants of the reversibility of beta-cell dysfunction.
39	Alfonsi et al., 2020 [56]	Carbohydrate Counting App Using Image Recognition for Youth With Type 1 Diabetes: Pilot Randomized Control Trial	Test the app's usability and impact on carbohydrate counting accuracy	Youth with type 1 diabetes	22	iSpy carbohydrate counting app	Carbohydrate counting accuracy, HbA1c levels	Machine learning for food identification	iSpy, a novel carbohydrate counting app, showed evidence of efficacy and high acceptability, supporting its use in diabetes care among youth with type 1 diabetes.
40	Ben-Yacov et al., 2023 [57]	Gut microbiome modulates the effects of a personalised postprandial-targeting (PPT) diet on cardiometabolic markers: a diet intervention in pre-diabetes	Explore the interaction between dietary changes, microbiome composition, and metabolic responses	Adults with pre-diabetes	200	Personalised postprandial-targeting diet vs. Mediterranean diet	Microbiome composition, cardiometabolic markers	Machine learning for diet response prediction	Supported the role of gut microbiome in modulating the effects of dietary modifications on cardiometabolic outcomes, advancing precision nutrition strategies for reducing comorbidities in pre-diabetes.
41	Lee et al., 2023 [58]	An Integrated Digital Health Care Platform for Diabetes Management With AI-Based Dietary Management: 48-Week Results From a Randomized Controlled Trial	Evaluate an integrated digital health care platform with AI-based dietary management for type 2 diabetes	Adults with type 2 diabetes	294	Integrated digital health care platform with AI-based dietary management	Glycemic control, weight loss	AI-driven dietary management	An integrated digital health care platform with AI-driven dietary management resulted in better glycemia and more weight loss in adults with type 2 diabetes.
42	Benhamou et al., 2019 [59]	Closed-loop insulin delivery in adults with type 1 diabetes in real-life conditions: a 12-week multicentre, open-label	Assess the effectiveness of the DBLG1 hybrid closed-loop system compared with sensor-assisted pump therapy	Adults with type 1 diabetes	68	DBLG1 hybrid closed-loop system	Time in glucose target range, hypoglycemic episodes	Machine-learning-based algorithm	The DBLG1 system improves glucose control compared with sensor-assisted insulin pumps, supporting the use of closed-loop

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Table 2 (*continued*)

SN	Author & Year	Title	Objective / Purpose	Population / Participants	Sample Size	Intervention / Exposure	Outcome Measures	AI/ML Model Used	Findings and Conclusions
		randomised controlled crossover trial							technology in adults with type 1 diabetes.
43	Zhao et al., 2022 [60]	Intelligent Algorithm-Based Ultrasound Image for Evaluating the Effect of Comprehensive Nursing Scheme on Patients with Diabetic Kidney Disease	Explore the effect of comprehensive nursing scheme on patients with diabetic kidney disease using ultrasound imaging	Patients with diabetic kidney disease	44	Comprehensive nursing scheme	Renal function, complications, quality of life	K non-local-means filtering algorithm for ultrasound imaging	Implementation of nursing intervention for diabetic kidney disease patients can effectively help patients improve and control renal function, and ultrasound images based on intelligent algorithm can dynamically detect these chang

the capabilities of AI to anticipate the onset and progression of diabetes-related conditions, assess risks of complications, and predict individual responses to various treatments or dietary interventions. By analysing diverse data, including lifestyle, environmental factors, and medical interventions, AI helps in identifying early indicators of diabetes risk [13,63]. For instance, studies have demonstrated AI's proficiency in predicting diabetes onset by analysing changes in the gut microbiome due to exercise or exposure to environmental chemicals [18,19]. Moreover, AI's predictive power extends to tailoring dietary strategies, evidenced by its ability to forecast responses to the Mediterranean diet or personalised nutrition plans, thereby enhancing glycaemic control [20,21]. It also plays a critical role in patient stratification, helping healthcare professionals customize treatment plans based on individual risks or likelihood of disease progression. This not only aids in preventive care but also ensures effective management of existing conditions [30,41,44]. Furthermore, AI contributes significantly to the innovation of medical devices, enhancing their functionality for more personalised diabetes management [32,50]. It's also pivotal in predicting acute events like hypoglycaemia, which is crucial for safe daily diabetes management [28,45]. Lastly, AI's scope includes forecasting long-term complications and evaluating the efficacy of interventions on insulin resistance, setting the stage for a future where healthcare is proactive, personalised, and predictive [31,52].

AI in Public Health Interventions focuses on the use of artificial intelligence to enhance public health strategies, particularly in assessing and managing the risk of diabetes and its associated cardiovascular complications. The findings from the studies in this domain provide insightful contributions to preventive health measures [64]. For example, Liu et al., 2020, highlighted the importance of exercise-induced changes in gut microbiota, correlating these changes with improvements in glucose homeostasis and insulin sensitivity in prediabetes. This study underscores the role of lifestyle factors in diabetes prevention and how AI can help identify effective preventive strategies based on individual microbiome profiles [18]. Similarly, Wei et al., 2022, demonstrated the predictive value of environmental chemical exposure in the onset of diabetes mellitus using machine learning. This approach emphasises the potential of AI in identifying broader environmental risk factors for diabetes, aiding in more comprehensive public health strategies [19]. On the other hand, Zou et al., 2024, and Sampedro et al., 2020, focused on the application of AI in stratifying patients based on their risk of diabetes progression and predicting complications like stent restenosis. These models assist in tailoring interventions and preventive measures more effectively [25,29]. Likewise, Oikonomou et al., 2022, and Wang et al., 2023, utilised AI to individualize cardiovascular care, demonstrating its utility in predicting the risk of heart failure and optimizing blood pressure control in patients with or without type 2 diabetes [30,33,41]. Khanji et al., 2019, did a similar work and identified predictive indicators for cardiovascular disease prevention, highlighting AI's role in improving the accuracy of prediction models for cardiovascular health management of diabetic patients [44]. Gastaldelli et al., 2021, also explored the impact of PPAR-γ agonists on steatohepatitis in patients with NASH, linking AI's potential in understanding complex biological responses to treatment and contributing to improved strategies for disease management [51].

AI in Prevention, Lifestyle, and Dietary Management represents a significant advancement in personalised healthcare, where artificial intelligence is leveraged to tailor dietary and lifestyle interventions to individual patient needs and preferences. Studies in this domain underscore the potential of AI in enhancing the management of diabetes and related metabolic disorders through personalised nutrition and lifestyle modifications [8,65]. AI's role in analysing vast amounts of data, from dietary patterns to gut microbiome composition, enables the creation of highly individualised dietary recommendations. For example, the use of digital twin technology and machine learning algorithms, as demonstrated in studies like Joshi et al., 2023, allows for the customization of nutrition plans that effectively address specific health issues, such as metabolic dysfunction-associated fatty liver disease [36]. The integration of AI with mobile health technologies, exemplified by the Keenoa app evaluated by Moyen et al., 2022, facilitates real-time tracking and assessment of dietary intake, offering patients and healthcare providers actionable insights for managing diabetes. These tools, through image recognition and other advanced technologies, make dietary monitoring more accessible and accurate [37]. Additionally, studies like those of Seethaler et al., 2022, and Popp et al., 2022, illustrate how AI can aid in understanding the complex interactions between diet, metabolic health, and individual physiological responses. This leads to more effective lifestyle interventions that are not just based on general dietary guidelines but are fine-tuned to each person's unique health profile [20,22]. AI's ability to predict long-term outcomes, as seen in the work of Saux et al., 2023, further adds value by helping patients and healthcare providers set realistic goals and track progress over time [34].

AI in Enhancing Clinical Decision-Making explores how artificial intelligence aids healthcare professionals in making more informed, precise, and tailored clinical decisions, significantly improving care quality for diabetic patients. The studies in this domain provide various insights into the practical applications and benefits of AI in diabetes management [66,67]. For instance, Liu et al., 2020, show how AI can discern the complex relationships between exercise-induced changes in the gut microbiome and improvements in glucose homeostasis, aiding in the design of effective exercise programs [18]. Similarly, Rein et al., 2022, demonstrate the potential of AI in personalizing diets to improve glycaemic control, offering a more nuanced approach to managing type 2 diabetes [21]. Moreover, studies like those of Zou et al., 2024, highlight how AI-based models can stratify patients by diabetes progression risks, optimizing intervention strategies [25]. Varga et al., 2021, compare various biomarkers for diabetes prediction, assessing the added value of AI in risk stratification over traditional methods [26]. Additionally, machine learning models, as developed by Faruqui et al., 2019, and Oikonomou et al., 2022, enable dynamic forecasting of blood glucose levels and individualised cardiovascular care of diabetic patients, respectively, enhancing the ability to anticipate and respond to patient needs [28,41]. In essence, these studies collectively highlight AI's potential in enhancing clinical decision-making by providing healthcare professionals with deeper insights, predictive capabilities, and personalised treatment strategies, thereby elevating the standard and effectiveness of diabetes care [68].

AI in Patient Engagement and Self-Management includes the use of AI-driven tools and platforms to enhance patient engagement, adherence to treatment plans, and effective self-management of diabetes. The studies in this domain demonstrate a range of innovative approaches that leverage AI to empower patients and personalize their care [69]. Liu et al., 2020, and Zhang et al., 2022, illustrate how AI can analyze complex biological and behavioural data to provide tailored advice, such as exercise programs that consider gut microbiota changes or identifying individual barriers to self-management in Type 1 Diabetes. This personalised feedback encourages patients to adhere more closely to their management plans [18,24]. Similarly, Rein et al., 2022, and Nayak et al., 2023, show the potential of AI in customizing dietary advice and insulin titration, respectively. By providing tailored recommendations based on individual glycaemic responses or offering voice-based conversational support for insulin management, AI enhances the patient's ability to make informed decisions and engage actively in their health management [21,47]. Tools like the PEPPER Adaptive Bolus Advisor, by Avari et al., 2021, and the Advanced Bolus Calculator for Type 1 Diabetes, by Unsworth et al., 2023, exemplify how AI can aid in precise and adaptive treatment decisions, thus supporting better glycaemic outcomes [32,50]. Additionally, platforms integrating AI-based dietary management and continuous glucose monitoring, by Park et al., 2020, provide real-time, actionable insights, fostering a proactive approach to diabetes self-management [53]. In essence, Domain 8 reflects a shift towards more interactive and personalised diabetes care, where AI tools not only inform and guide patients but also adapt to their unique needs and preferences, promoting better health outcomes through enhanced engagement and self-management [10,68].

Conclusion and recommendations

The integration of AI in diabetes care marks a transformative shift, offering personalised, efficient, and proactive solutions. This review reveals AI's enhancement of diabetes management across eight key domains, improving care accuracy and efficiency. AI empowers patients with superior self-management tools and deepens the understanding of diabetes as a complex condition.

Accordingly, the review recommends that 1) there should be ongoing investment in research, development, and large-scale implementation studies to integrate AI successfully into healthcare. 2) It's critical to ensure robust data security and privacy, necessitating standardized protocols for data handling. 3) Interdisciplinary collaboration is essential, involving healthcare professionals, AI researchers, and policymakers to develop AI tools that are user-friendly, clinically relevant, and aligned with healthcare policies. 4) AI solutions must be designed with patient needs in mind, and regulatory frameworks should be established to oversee ethical deployment, addressing issues like algorithmic bias and accountability. 5) Education and training for healthcare professionals are crucial for effectively integrating AI into clinical practice and communicating its benefits and limitations to patients. 6) Continuous monitoring and evaluation of AI applications are necessary to identify areas for improvement, understand long-term impacts, and adjust strategies in response to emerging data and technologies.

Declaration on the use of AI in the writing process

The authors of this manuscript declare that in the writing process of this work, no generative artificial intelligence (AI) or AI-assisted technologies were used to generate content, ideas, or theories. We utilized AI solely for the purpose of enhancing readability and refining language. This use was under strict human oversight and control. After the application of AI technologies, the authors carefully reviewed and edited the manuscript to ensure its accuracy and coherence. The authors understand the potential of AI to generate content that may sound authoritative yet might be incorrect, incomplete, or biased. Considering this, the authors ensured that the manuscript was thoroughly revised by human eyes and judgment. In line with Elsevier's Authorship Policy, the authors confirm that no AI or AI-assisted technologies have been listed as an author or co-author of this manuscript. The authors fully comprehend that authorship comes with responsibilities and tasks that can only be attributed to and performed by humans, and authors have adhered to these guidelines in the preparation of this manuscript.

CRediT authorship contribution statement

Mohamed Khalifa: Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Mona Albadawy:** Writing – original draft, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare no conflicting interests to declare regarding the publication of this manuscript.

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