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Artificial Intelligence: The Future for Diabetes Care

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ABSTRACT

Artificial intelligence (AI) is a fast-growing field and its applications to diabetes, a global pandemic, can reform the approach to diagnosis and management of this chronic condition. Principles of machine learning have been used to build algorithms to support predictive models for the risk of developing diabetes or its consequent complications. Digital therapeutics have proven to be an established intervention for lifestyle therapy in the management of diabetes. Patients are increasingly being empowered for self-management of diabetes, and both patients and health care professionals are benefitting from clinical decision support. AI allows a continuous and burden-free remote monitoring of the patient's symptoms and biomarkers. Further, social media and online communities enhance patient engagement in diabetes care. Technical advances have helped to optimize resource use in diabetes. Together, these intelligent technical reforms have produced better glycemic control with reductions in fasting and postprandial glucose levels, glucose excursions, and glycosylated hemoglobin. AI will introduce a paradigm shift in diabetes care from conventional management strategies to building targeted data-driven precision care.

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KEYWORDS: Artificial intelligence (AI); Diabetes; Machine learning; Management; Prediction

INTRODUCTION

Diabetes, a chronic metabolic condition, is a global health care burden. According to the International Diabetes Federation (IDF), 463 million people between ages 20 and 79 years have diabetes, and 374 million have impaired glucose tolerance.[1] By the year 2045, 693 million people are likely to have diabetes.[2] While 8.8% of the world population was reported to have diabetes in 2017, the numbers are projected to rise to 10% by 2045.[3]

Diabetes is associated with various complications and a significant morbidity and mortality.[4] It is important to intervene not only to treat but also to prevent and make a timely detection of diabetes. Management of diabetes is challenging because 1 of 2 adults with diabetes are undiagnosed, yet 10% of global health expenditure (US$760 billion) are spent on diabetes.[1]

Artificial intelligence (AI) finds widespread use in four key areas in diabetes care, including automated retinal screening, clinical decision support, predictive population risk stratification, and patient self-management tools.[5,6] The purpose of this review is to provide an overview of the scope and utility of AI in the prevention, diagnosis, and treatment of diabetes.

Artificial Intelligence

AI has been described as "a branch of computer science that aims to create systems or methods that analyze information and allow the handling of complexity in a wide range of applications."[7] The application of AI to diabetes is feasible and desirable for efficient data handling and the development of tools and devices for its management. To provide safer technology through AI, it is recommended to have safe designs, safety reserves, and procedural safeguards, with all uncertainties identified for all potential technical systems.[8]

Technical advances have introduced wearables, smartphones, and other gadgets that can aid in the continuous monitoring and tracking of patients symptoms and disease status. Physicians and health care professionals should

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allow patients to choose AI-assisted care for the effective management of diabetes.[9]

AI can influence and improve 3 main domains of diabetes care: patients with diabetes, health care professionals, and health care systems (Figure 1). AI has added newer dimensions of self-care for patients with diabetes, introduced rapid and reliable decision making and flexible follow-ups for health care providers, and optimized resource utilization in health care systems.

The US Food and Drug Administration has approved IDx-DR, a device that uses an AI algorithm, to analyze digital retinal images and aids the early detection of retinopathy.[10] The American Diabetes Association (ADA) is supporting the use of AI in diabetes care. The ADA has recognized the use of autonomous AI for the detection of diabetic retinopathy and macular edema.[11]

AI allows patients to be informed and empowered. Digital solutions have a huge impact on health care systems as influences patient comorbidities, behaviors, time spent in health care facilities, and the need for frequent travel to and contact with health care providers.[12] AI has also improved the patient flow to the hospital and patient transfer within a hospital.[13]

Online diabetes communities and support groups offer a chance for patients to connect and learn from the experience of others. This collaborative method of learning more about the various aspects of the disease is engaging for patients and caregivers and has a positive impact on desired outcomes and well-being of patients.[14]

CLINICAL SIGNIFICANCE

- Artificial Intelligence (AI) will cause a paradigm shift in diabetic management through data-driven precision care.
- AI has changed the way diabetes is prevented, detected, and managed, which can help in bringing down the global prevalence of 8.8%.
- Case-based reasoning, machine learning, deep learning, and neural networks enable predictive population risk stratification, automated retinal screening, enhanced decision making, and self-management.
- AI positively impacts medical professionals by supporting decision making and remote monitoring.

Early detection of diabetic retinopathy using AI is a cost-effective alternative to reduce the ophthalmic complications and preventable blindness associated with diabetes.[15] Continuous glucose monitors (CGMs) have the potential to reduce health care costs for diabetes.[16] The use of image-based screening of retinal changes and diabetic foot ulcers can avoid delays in referral for specialized care and improve the quality of life by enabling earlier and timely intervention.[9]

Techniques

Several AI-based techniques have been applied in diabetes care. With the advent of AI, the diagnosis of diabetes has evolved beyond a few measurements of blood glucose levels and glycosylated hemoglobin (HbA1c).

Case-based reasoning (CBR). CBR, an AI technique to solve new problems based on learning from similar past encounters, is being extensively used in diabetes management.[17,18] The 4 Diabetes Support System is an example of CBR that has been used in diabetes care. The system aims to automatically detect problems in control of blood glucose, propose solutions to the detected problems, and remember the effective and ineffective solutions for individual patients.[17] CBR has been used to optimize and individualize insulin therapy for various meal situations in diabetes.[19]

Machine learning and deep learning. Several machine learning processes have been used to build digital support in diabetes care. These include support vector machine,

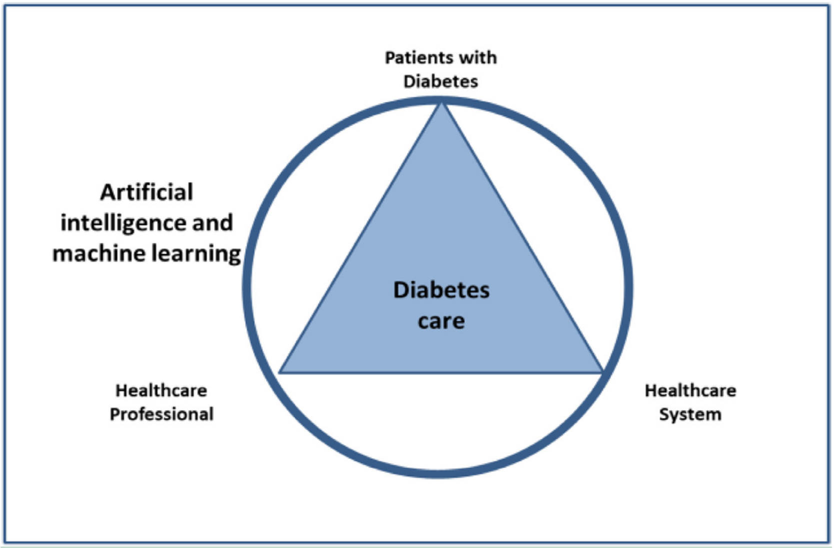

Figure 1 Scope of artificial intelligence and machine learning in diabetes care.

artificial neural network, naïve Bayes, decision tree, random forest, classification and regression trees, and k-nearest neighbor.[6] Machine learning has been applied to create automated screening for blood glucose variability.[17] Principles of machine learning, including feature selection techniques (eg, random forest, logistic regression, mutual information, principal component analysis, analysis of variance, and Fisher discriminant ratio), outlier removal techniques, cross-validation protocols, and classifiers (eg, linear discriminant analysis, quadratic discriminant analysis, naïve Bayes, Gaussian process classification, support vector machine, artificial neural network, Adaboost, logistic regression, decision tree, and random forest) have been used to accurately stratify the risk of diabetes and identify patients with diabetes and controls).[20]

Machine learning programs can identify people at high risk for diabetes based on genetic and metabolic factors.[9]

Artificial neural networks. Neural networks have been created to link and analyze disparate information and build personalized solutions. Neural network methodology has found particular and vast applications in diabetes diagnosis.[21] Intelligent algorithms have been constructed to study the impact of various factors on glycemic indices.[9]

Others. Other techniques like support vector regression (SVG) have been applied to diabetes care. Support vector regression has been used to build a hypoglycemia predictor. This creates an alert for preventive intervention when patients have alarmingly low levels of blood glucose.[17] Together, these technologies find wide application in diabetes care (Figure 2).

APPLICATIONS

Automated retinal screening. Deep learning algorithms have been developed to automate the diagnosis of diabetic retinopathy.[22] AI-based screening of retina is a feasible, accurate, and well-accepted method for the detection and monitoring of diabetic retinopathy. A high sensitivity and specificity of 92.3% and 93.7%, respectively, have been reported for automated screening of the retina. Patient satisfaction for automated screening is also high with 96% patients reported as being satisfied or very satisfied with this method.[23] Convolutional neural networks (CNN) have been trained on limited data sets to generate lesion-specific probability maps for hemorrhages, microaneurysms, exudates, neovascularization, and normal appearance in the retina.[24]

Clinical decision support. Supervised machine learning-based clinical decision support tools have been developed to predict short- and long-term HbA1c response after insulin initiation in patients with type 2 diabetes mellitus. These tools also help to identify clinical variables that can influence a patient's HbA1c response. The elastic net regularization-based generalized linear model based on baseline HbA1c and estimated glomerular filtration rate is reported to reliably predict the HbA1c response after insulin initiation. Areas under the curve (AUC) of 0.80 (95% confidence interval [CI] 0.78−0.83) and 0.81 (95% CI 0.79−0.84), respectively, are reported for short. and long.term HbA1c response.[25] Machine learning has been used to develop an intuitive approach for customizing interventions in medication adherence and predicting the risk of hospitalization in diabetes. In a retrospective cohort study (n = 33,130), machine learning

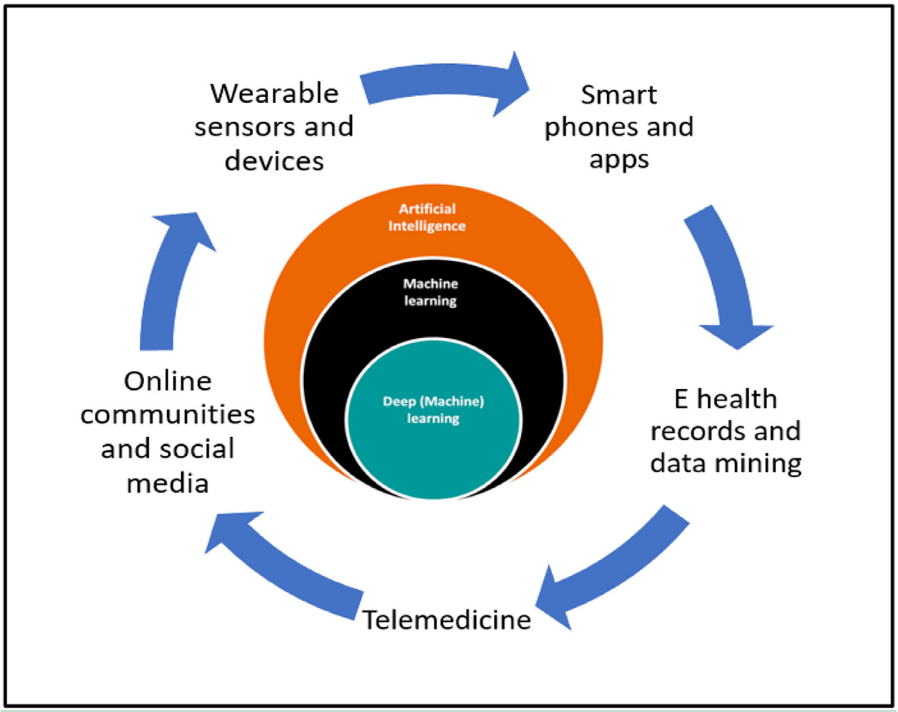

Figure 2 Applications of artificial intelligence in diabetes care.

yielded adherence thresholds of 46% to 94% as most discriminating for risk of all-cause hospitalization. This study confirmed the variability of predictive adherence thresholds according to patient characteristics and complexity of medications.[26]

Predictive population risk stratification. Healthcare recommendation system (HRS) using machine learning helped to predict the risk for a disease, including diabetes, by analyzing patient's lifestyle, physical health factors, mental health factors, and their social network activities. Data from 68,994 healthy people and patients with diabetes has been used as a training data set for using decision tree, random forest, and neural networks to predict diabetes with high accuracy (accuracy = 0.8084 with all attributes).[27]

Predictive models have been built to leverage big data analytics for building estimates of possibility of development of complications in patients with diabetes. Many such models have been developed to predict the development of both long-term (eg, retinal, cardiovascular, and renal) and short-term (ie, hypoglycemia) complications of diabetes.[28] Trained to interpret images of feet, mobile apps have been introduced to follow-up with patients with diabetes for development of diabetic foot ulcers.[29]

Machine learning has been used to develop decision tree models for prediction of development of type 2 diabetes mellitus in pregnant women with gestational diabetes. The discriminative power of this prediction method was 83.0% in the training set and 76.9% in an independent testing set, making it superior to conventional monitoring of fasting glucose levels.[30]

Genomics. Advanced molecular phenotyping, genomics, epigenetic alterations, and development of digital biomarkers is a new advance in the diagnosis and management of disease conditions.[31] These can be applied to diabetes where huge data sets are generated owing to the heterogenous nature and chronic course of the disease. Microbiome data has been used to build a repository of microbial marker genes that can be used to predict the possibility of development of diabetes and guide the treatment in patients with confirmed diabetes.[32] Genome-wide association studies have identified more than 400 signals that could potentially establish the genetic susceptibility to diabetes.[33] Convolutional neural networks models have been trained on multiple genome-wide mapping and regulatory epigenomic annotations available for pancreatic islets to predict regulatory variants for refining the signals associated with diabetes.[34]

Patient self-management tools. Self-management is the key to the treatment of diabetes. With the advent of AI, patients are empowered to manage their own diabetes, generate data for their own parameters, and be their own experts for health.

Increased awareness: Digital platforms allow a targeted education of patients with diabetes. Awareness and knowledge about eating habits and activity patterns are now available through web-based programs and mobile phone and smartphone apps.[35] This has been particularly useful in the management of diabetes in pregnant women. A web-based intervention was reported to increase the knowledge of gestational diabetes and proved to be a good adjunct to the management of diabetes in 21 women.[36]

Self-treatment: AI allows patients with diabetes to take daily decisions for diet and activity. Apps have been used to allow patients to assess the quality and calorie value of food intake. Accountability for diabetes care is enhanced when patients capture a picture of their own food and assess what they eat.[37]

Digital therapeutics has been evaluated in the management of diabetes. In a 12-week interventional study, 118 adults with type 2 diabetes mellitus received a digital intervention (FareWell) via an app and a digitally delivered specialized human support in the form of coaching every 2 weeks via telephone. The aim of the intervention was to evaluate a sustainable shift to plant-based diet and regular exercise. All patients had HbA1c >6.5% at baseline and 28% patients achieved HbA1c <6.5% at the end of the study. At 12 weeks, >86% participants were still using the app, and a total of 57% achieved a composite outcome of reducing HbA1c, reducing diabetic medication use, or both. Patients showed good acceptance for the app, with 92% reporting greater confidence in the management of their diabetes compared to that prior to participating in the study.[38]

The One Drop Mobile app was designed to help schedule medication reminders, view statistics, set goals, track health outcomes, and get data-driven insights in patients with type 1 and type 2 diabetes. Total of 1288 patients reported a 1.07% to 1.27% absolute reduction in HbA1c during a median 4 months of using the app. The use of One Drop Mobile app for tracking self-care was associated with improved HbA1c in patients with diabetes.[39]

Other applications. Telehealth has revolutionized the management of diabetes. Remote monitoring reduces the time spent in follow-up visits and allows a more real-time monitoring of the glycemic status as well as the overall health of the patient. AI has the ability to replace 50%-70% of routine follow-up clinical consultations with virtual engagements and remote monitoring.[12] Short message service (SMS) text messaging are being tested for improvement in medication adherence in a randomized control trail in over 800 patients with type 2 diabetes mellitus in sub-Saharan Africa.[40]

Other devices. Diet and exercise are the initial and effective strategies to prevent type 2 diabetes mellitus in high-risk individuals.[41] Various apps have been designed that provide customized dietary plans and schedules and suggest alterations in food intake to suit an individual's lifestyle. Daily activity levels can be tracked by wearables that record step counts and time and intensity of other activities.[42] Wearable devices are effective facilitators of changes in behavior toward health.[43] These devices enable tracking of daily activity and can motivate an individual to include a targeted activity into routine to prevent chronic diseases, including type 2 diabetes mellitus.

Several apps are also designed to analyze the image of food and provide details of the nutrient and calorie value of food. These apps can help to keep a check on body weight and prevent obesity, an established predecessor to type 2 diabetes mellitus.[42] Web-based programs provide knowledge about diet and physical activity and patients can log in their daily intake and activity data and gain continuous feedback.[35]

End Users

The end users of technical advances in diabetes care include health care professionals in hospitals, diabetes management centers, and research institutes. Electronic health records (EHR) allow consistent and homogenous data capture and increased access to data. EHRs are being tapped as data repositories to train and develop algorithms for the prediction, detection, and management of diabetes.[44] Patients represent a significant end user of AI-based advances for the management of diabetes and have embraced technical advances with fervor. Technical advances have simplified the management of diabetes and enabled patients to efficiently operate and execute the required management strategies. Better glycemic control is reported with the use of mobile apps in the management of type 2 diabetes mellitus. In a systematic review of 14 studies (n = 1360), the use of mobile apps resulted in a mean reduction in HbA1c of 0.49% (95% Cl 0.30, 0.68; I^2 = 10%) when compared with controls.[45] In another recent meta-analysis of 21 studies (n = 1550), mean HbA1c reductions of 0.49% (95% CI, 0.04-0.94; I^2 = 84%) and 0.57% (95% CI, 0.32-0.82; I^2 = 77%) were reported for type 1 and type 2 diabetes, respectively.[46]

Limitations of Artificial Intelligence

The application of AI in diabetes care has several limitations.

Human factors. Factors influencing the use of AI in diabetes care have been evaluated in some studies. In a meta-analysis of 14 randomized control trials, younger patients were reported to attain greater benefits from mobile apps for diabetes care and the effect size was enhanced with health care professional feedback.[45] AI can pose a risk of de-skilling physicians by introducing dependence. This may introduce a vicious cycle of inadequate accuracy because AI in itself requires periodic refinements by experts.[9]

Technical factors. Barriers for the use of AI in diabetes care include cost, access, and implementation. With a growing array of devices and apps, interoperability is reported as a common potential barrier to their use in diabetes management.[12]

Limitations of data. Paucity of supporting data to build logical and accurate algorithms is a common challenge in diabetes care. Data sets will need to be more mature and structured to inform digital applications to construct impactful solutions. Concerns about security and data protection and regulatory concerns are also limiting the seamless adoption of technology in diabetes care.

Limitations of design. Current models and applications of AI in diabetes care have been validated using retrospective data sets. Prospective validation of these technical advances holds promise for automating diabetes care.[9] Endpoints in clinical studies will need to be redefined to include the digital biomarkers and data from apps and monitors and activity trackers.

SUMMARY

AI is attracting attention for the management of diabetes. AI enables us to rethink diabetes and redefine the strategies for prevention and management of diabetes.

AI supports the development of prediction models to estimate the risk of diabetes and its related complications. This will help to bring in an element of personalized care in the management of diabetes. Patients are now being empowered to manage their own health and physicians can provide a timely and targeted intervention through technical platforms. These advances save time and cost because data can be collected remotely and virtual management is replacing the routine visits to a clinic.

AI has introduced a quantum change in diabetes care and will continue to evolve. Going further, broader experience generated from the continuous use of AI will help to standardize the functionality and utility in diabetes care.

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