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REVIEW

Mathematical Modelling for Community Based Intervention for Managing Diabetes: A Systematic Literature Review

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Abstract: Diabetes mellitus (DM) poses a significant global health and economic challenge. Effective diabetes management requires a multifaceted approach that combines clinical and community-based interventions. Community-based interventions are critical to address the growing burden of diabetes. Despite numerous independent studies on community-based interventions for T2DM management and mathematical models, there has been no comprehensive review integrating these two domains. This systematic literature review aimed to fill this gap by examining mathematical modelling in the context of community-based interventions for T2DM management. Following the PRISMA guidelines, relevant articles were identified, screened, and assessed for eligibility using the Scopus, ScienceDirect, and PubMed databases. The inclusion criterion was English-language research articles published between 2014 and 2024 that focused on T2DM interventions using mathematical models. Seven articles met the final inclusion criteria and were analysed to answer research questions related to the geographical origin of the data, nature of the intervention, specific mathematical model used, and the main findings of the primary study. This review highlights that mathematical models are critical for optimising community-based interventions, by identifying key risk factors, predicting disease progression, and evaluating the effectiveness of various treatments. By synthesising findings from different geographical and economic contexts, this review highlights the importance of culturally and contextually relevant strategies for diabetes management. The integration of robust mathematical models with community-based approaches promises to develop more effective evidence-based strategies for diabetes management, particularly in resource-limited settings.

Keywords: mathematical model, diabetes mellitus type 2, community-based intervention

Introduction

Diabetes, a metabolic disorder characterised by elevated blood glucose levels, arises from the inability of an individual to effectively produce or utilise insulin.[1–3] According to its aetiology and clinical presentation, the disease is broadly classified into three categories including Type 1 Diabetes Mellitus (T1DM), Type 2 Diabetes Mellitus (T2DM), and gestational diabetes, with Type 2 Diabetes Mellitus (T2DM) accounting for most cases globally.[4,5] Unlike Type 1 Diabetes Mellitus (T1DM), which usually appears in childhood and results from autoimmune damage to insulin-producing cells, T2DM is often associated with lifestyle factors.[1,2] In low-and middle-income countries, T2DM is caused by factors such as inadequate nutrition and environmental conditions, infections, limited resources, and inaccessible health care services.[6,7]

The global burden of T2DM is rapidly increasing, with the most significant increase occurring in low-income and middle-income countries (LMICs).[8–10] The extended and expensive treatment of T2DM frequently leads to financial hardship, causing millions to fall into poverty annually, impeding developmental efforts.[11,12]

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Diabetes mellitus presents a significant global health challenge, requiring new strategies to improve patient outcomes. Conventional approaches "one size fits all" have proven inadequate in managing the diverse nature of the disease.[2] Factors associated with diabetes prevalence and outcomes are multidimensional, and a growing number of studies have shown that diabetes is not only biologically determined, but also strongly influenced by broader social factors.[13] The effective management of diabetes requires a multifaceted approach that addresses both clinical and community-based interventions. Existing research has highlighted the need for community-based interventions to address the growing burden of diabetes, particularly in low- and middle-income countries (LMICs) where access to healthcare resources may be limited.[2] According to Budreviciute et al (2020), the primary barrier to reducing non-communicable diseases, including T2DM, in low- and middle-income countries lies in the absence of tailored prevention strategies, emphasising the necessity of bespoke approaches rather than adopting models designed for wealthier nations.[14]

Several scholars have suggested interventions as prevention strategies in low-and middle-income countries, including educational initiatives, the utilisation of[15–18] m-health or telehealth,[17,19–23] and community health assessment programs.[24–27] Ideally, community-based interventions should be holistic and multi-faceted in their approach.[28] Pardoel et al (2021) identified various components of community-based interventions in their review including family support, education, physical exercise, telehealth, peer support, lifestyle advice, and storytelling. They highlighted telehealth as promising, particularly in rural areas with limited healthcare facilities, and storytelling as effective, particularly in contexts of low health literacy.[29]

White et al (2024) conducted a systematic review and meta-analysis of the combined effects of clinician-led and community-based group exercise interventions on a range of health outcomes in adults with type 2 diabetes and reported that the intervention strategies implemented provide substantial health benefits for managing key type 2 diabetes mellitus-related health parameters. These findings, in combination with further research, could inform the refinement of physical activity guidelines for individuals with type 2 diabetes mellitus, advocating supervised group exercise in community settings.[30] A recent systematic review by Spurr et al (2024) outlined various community-based interventions targeting indigenous youth in multiple areas heavily populated by indigenous communities across the USA and Canada.[31] They emphasised the significance of comprehending the cultural suitability and relevance of lifestyle interventions. Kobashi et al (2024) also proposed expanding outreach to patients with DM by employing non-healthcare personnel to administer educational programs.[32]

Mathematical modelling can be employed to assess the outcomes and impacts of community-based interventions. Mathematical modelling has become an important research tool for exploring complex systems, particularly for understanding the functioning and optimisation of health systems.[33,34] Mathematical models are increasingly used to aid decision-making in public health. The results of mathematical modelling studies can provide evidence that a systematic review of primary studies is insufficient to draw conclusions or support recommendations for guidelines. For example, mathematical modelling has been used to inform guideline recommendations on tuberculosis (TB) control in healthcare facilities.[34] One study reported that mathematical modelling studies were used to create 46 WHO guidelines (29.9%) and 101 other recommendations (6.2%).[35] The application of mathematical modelling in the field of health can be particularly beneficial when considering chronic diseases, where strategies for the management of these diseases focus on three main courses of action: prevention, prognosis, and therapy.[36] Thus, mathematical models allow for the identification of key risk factors for disease progression, highlight patterns of disease progression, and test the effectiveness of treatments or therapies in patients.

Over the past decade, studies on mathematical modelling for healthcare have become increasingly prevalent and integral to decision-making in global public health, especially during the COVID-19 pandemic.[34] Mathematical modelling studies exemplify diverse applications, including: i) assessing new diagnostic tools for screening programs; ii) forecasting outbreaks to inform public health responses[37] iii) projecting the long-term impact of interventions on specific populations and potential secondary benefits eg, preventive care screening, vaccine introduction[38] or iv) evaluating the economic implications and cost-effectiveness of decisions.[39]

Although many reviews have extensively discussed community-based interventions[30–32] and mathematical modelling in the management of diabetes mellitus,[40–42] a comprehensive review integrating these two important aspects is still lacking. Our systematic literature review addressed this gap by providing an in-depth review of mathematical models in the context of community-based interventions for diabetes mellitus management. This dual focus is particularly important as it not only highlights the potential of community-based approaches in diabetes management but also underscores the importance of a robust mathematical model for optimising these interventions.[43] A review of these two areas may pave the way for more effective evidence-based strategies for diabetes control and policy development.[31,32]

Materials and Methods

The methodology used to select articles for this systematic literature review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. PRISMA comprises of three main stages: identification, screening, and eligibility.[44]

In the identification phase, relevant articles were searched in three databases: Scopus, Science Direct, and PubMed, using specific keywords. These keywords were combined with a Boolean logical operator to ensure a thorough search process. The PRISMA search terms were as follows: ("MATHEMATICAL MODEL" OR "MATHEMATICAL MODELING" OR "MATHEMATICAL MODELLING") AND "DIABETES MELLITUS" AND ("INTERVENTION" OR "MANAGEMENT" OR "PROGRAM")).

Inclusion and Exclusion Criteria

During the screening phase, the articles identified from various databases were entered into the Mendeley Reference Manager to eliminate duplicates. Duplicate entries were eliminated using Scopus search results as a baseline. The titles and abstracts of each article were then evaluated for relevance, including a research article published in English between 2014 and 2024, focusing on T2DM and discussing diabetes intervention using mathematical models. Grey literature, which refers to materials that are not peer-reviewed or formally published in scientific journals, was not included. The accessibility criteria were verified at this stage.

Articles that passed the screening stage underwent a comprehensive evaluation in the eligibility phase to confirm their relevance to the research topic, mathematical models of community-based interventions for diabetes mellitus. Following these stages, the selected articles formed the basis of the systematic literature review. A flowchart illustrating the selection process of the studies included in this review is presented in Figure 1.

Research Questions

Following the definition of mathematical modelling by Porgo et al (2019), we define the mathematical modelling "as a study that uses mathematical modelling to address specific research questions" which in our study is the impact of community-based interventions in health care facilities to control T2DM.[34] This study investigated mathematical modelling in the context of community-based interventions for T2DM management. The seven research questions and their purpose are listed in Table 1.

Results

The literature review explores mathematical models applied to diabetes interventions, focusing on their geographic context, methodologies, data types, integrated interventions, and outcomes. The initial literature search yielded 290 records from the three databases. After removing the duplicate entries, 249 abstracts were screened. Furthermore, 249 articles identified through the PRISMA search results were consolidated and their keywords were analysed using VOSviewer, an effective tool in library science research. This analysis provides valuable insights and a comprehensive overview of the scientific publications. The findings were visualised to illustrate the content and patterns of PRISMA search results. This visualisation aids in assessing the prominence of keywords and their frequency across the gathered articles. The circles represent the keywords identified in the articles, with larger circles indicating a higher frequency of their appearance. The lines connecting the circles depict the relationships between the keywords.

The outcome of this analysis, revealing a strong association between mathematical models, human subjects, age, clinical studies, and diabetes mellitus (Figure 2). The most frequently occurring keywords are "human" (217 occurrences), "mathematical model" (197 occurrences), "age" (136 occurrences), "gender" (129 occurrences) and "diabetes mellitus" (113 occurrences). It is logical to assume that diabetes mellitus is associated with gender and age. Wild et al (2004) concluded that diabetes is more prevalent among men than among women, yet more women are affected by

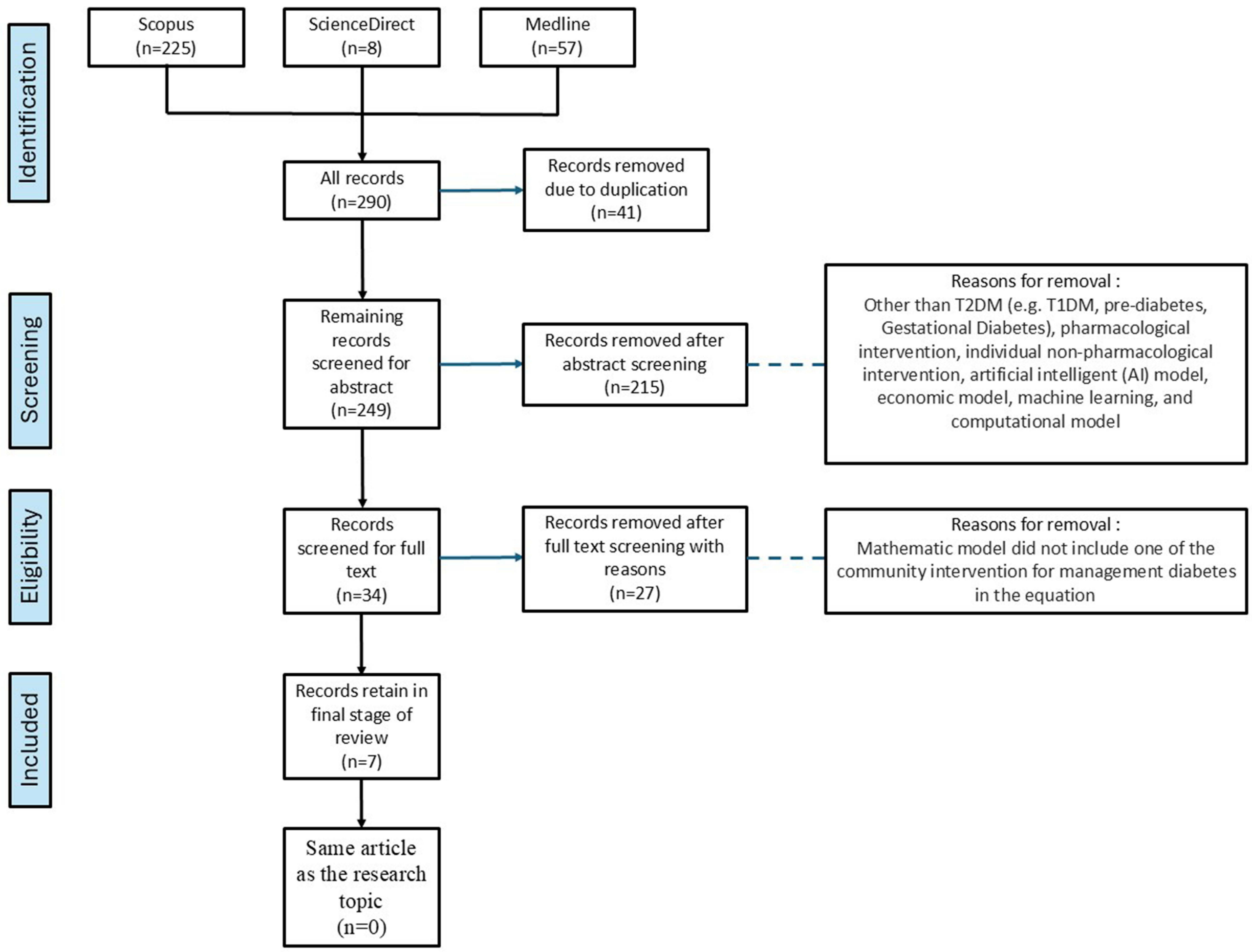

Figure 1 PRISMA Flow-chart illustrating the selection process for studies included in this review. Adapted from Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:71. doi:10.1136/bmj.n71. Creative Commons.[44]

diabetes, and that the most significant demographic shift influencing diabetes prevalence seems to be the rising proportion of people aged 65 years and older.[45]

Furthermore, various keywords associated with diabetes mellitus are depicted in Figure 3. Many keywords are pertained to pharmacological interventions, such as "glucose blood level" (174 occurrences), "insulin sensitivity" (109 occurrences)

Table 1 Research Questions

Questions	Purposes
Where are the geographic locations from which the data for the mathematical models originate?	Geographic location helps in comprehending the context of the intervention, with economic and cultural factors adding unique dimensions to the discussed intervention.
Which type of study and methodology is used in the study	The type of study and methodology help assess the robustness of the study's design, and how the results can be interpreted or generalized.
What kind of data are employed in the study	The type of data can be used to determine the reliability and validity of the findings, also it helps in comprehending the scope and limitations of the study.
What interventions are integrated into the mathematical model?	The type of intervention is crucial because many studies only provide projections, suggesting that eliminating one or more risk factors could reduce diabetes mellitus prevalence without detailing the intervention itself.

(*Continued*)

Table 1 (Continued).

Questions	Purposes
Which specific mathematical model is employed in the study	Due to the diverse usage of essential terminology, and the potential for certain terms to carry different interpretations, it was crucial in the review to provide detailed descriptions of each modelling approach.
What are the quantitative findings of the study	Quantitative findings provide numerical data that can be analysed to determine relationships, trends, or patterns. This helps to assess the strength, significance, and generalizability of the study's conclusions.
How is the result of the study	From the result of the study, the mathematical model can be analysed to explore its potential applications in various scenarios.

and "major clinical study" (90 occurrences). Among the articles retrieved, a few focused-on interventions related to diabetes management, including "health care cost" (18 occurrences) and "cost benefit analysis" (17 occurrences).

Figure 4 shows the keywords used in the mathematical model. Among the types of interventions mentioned earlier related to diabetes management, only "exercise" appeared 11 times. To maintain clarity, only keywords that appeared 10 or more times were displayed on the map. Other types of interventions are not shown in Figure 4 because they appeared fewer than 10 times in the articles gathered. This finding indicates a potential gap in research addressing holistic or lifestyle-based management strategies.

From the initial pool, 34 articles underwent full-text review, leading to the final selection of seven key studies for in-depth analysis and discussion (Figure 1). Finally, seven scientific papers were retained for further discussion and are summarised in Table 2. Geographically, the studies span diverse locations, including India, Bangladesh, and Qatar, reflecting varying cultural and economic contexts that influence intervention strategies. Methodologically, the studies

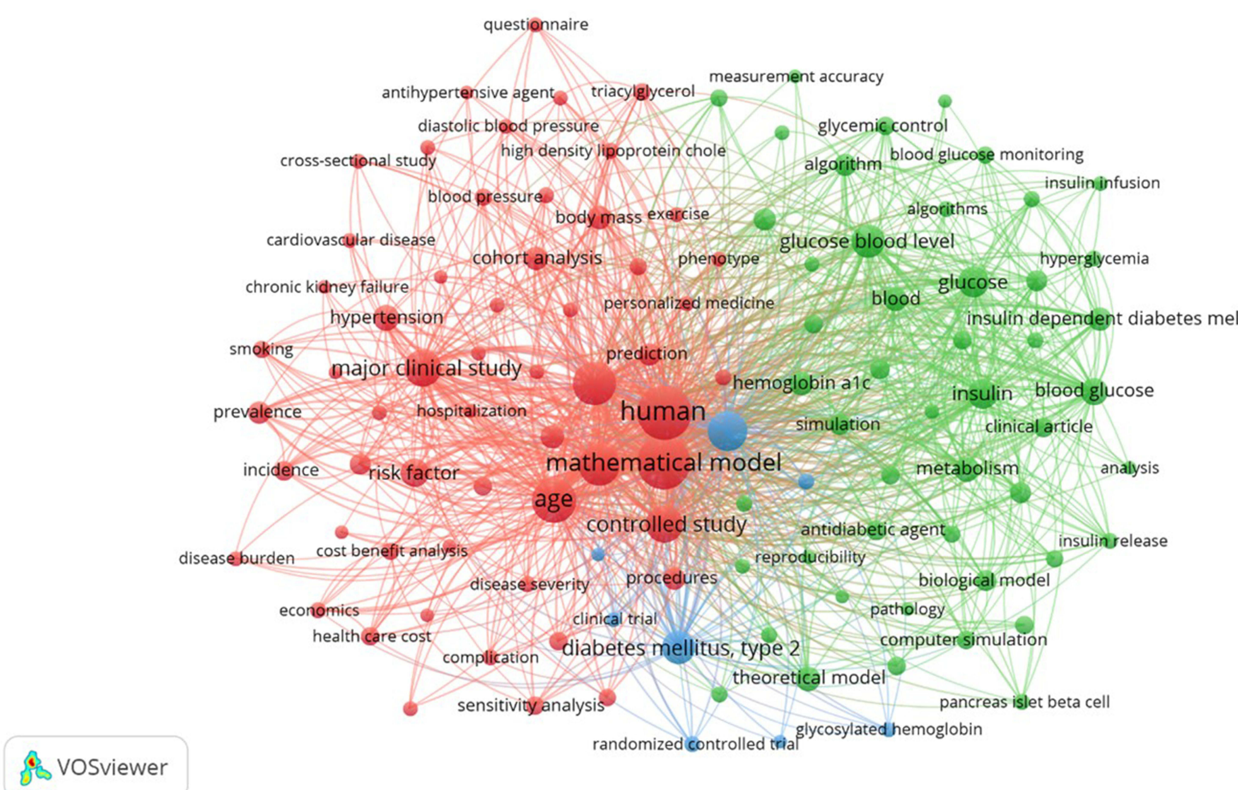

Figure 2 Keyword mapping using VOSviewer.

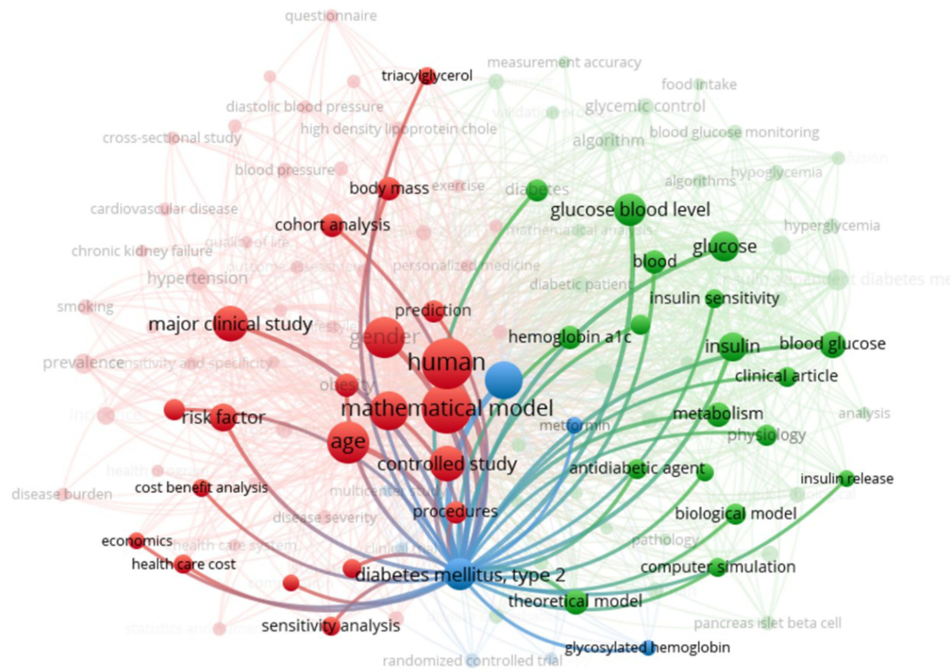

Figure 3 Keywords connected to diabetes mellitus, type 2.

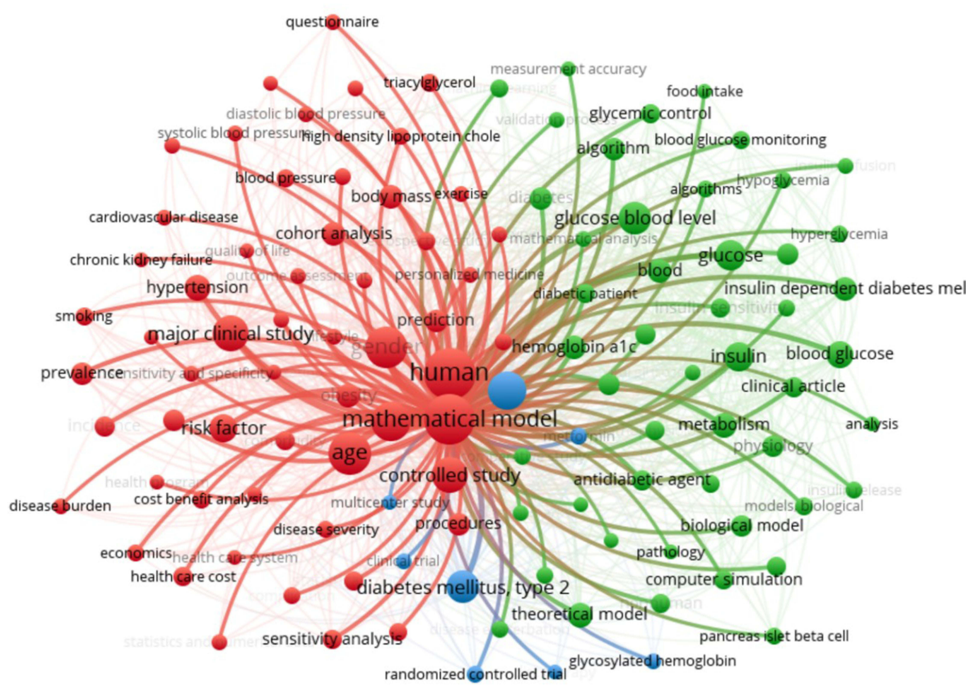

Figure 4 Keywords connected to mathematical model.

employ robust approaches such as linear optimization, deterministic modelling, fractional-order derivatives, and system dynamics, providing flexibility in addressing diabetes management challenges. Data types range from secondary data sources like national surveys and dietary records to individual-level data from continuous glucose monitoring devices, ensuring a balance of population-wide insights and personalized analyses.

Table 2 Summary of Studies

Author	Years	Location	Type of Study and Methodology	Type of Data Used in Analysis	Type of Intervention	Mathematic Model	Quantitative Findings	Results
Awad et al[46]	2019	Qatar	Deterministic modeling for public health in Qatar	Population-based demographic data	Reduce Smoking, reduce Obesity, reduce Physical Inactivity	Ordinary differential equations	WHO interventions reduced T2DM prevalence by 12% by 2050. Combined strategies reduced prevalence by 44.5%, averting up to 38,379 cases and preventing 14% of related deaths. Subsidies and physical activity interventions also showed significant impacts on reduction rates.	By focusing on and lowering the occurrence of obesity, smoking, and physical inactivity. It is projected that Qatar could prevent up to 46% of future T2DM cases and 14% of T2DM-related deaths by 2050
Paidipati et al[47]	2021	India	Linear optimization models for dietary optimization	Dietary data from 62 recipes in India	Diet management	Linear programming problem	Menus optimized to reduce calorie intake while maintaining nutrient requirements. Optimized calories ranged from 1096.4 to 1986.8 kcal across six menus, ensuring reduced glycaemic impact for diabetes management.	The goal programming methods aimed to maximize the allocation of food recipe based on calories while minimizing deviations in achieving nutrient goals
Mollah & Biswas[48]	2023	n/a	Deterministic modeling with optimal control theory	Population-level simulations and parameters from literature	Education and treatment	Ordinary differential equations	Media awareness campaigns alone reduced T2DM complications by 35.01 million cases with a disease averted ratio (DAR) of 394.82. Treatment reduced 95.09 million cases (DAR: 1.9504), and combined approaches averted 130.08 million cases with an incremental cost-effectiveness ratio (ICER) demonstrating cost efficiency.	The model treats awareness and saturated treatment as time-dependent control parameters in an optimal control framework to evaluate complications and financial costs associated with T2DM.
Ferdous[49]	2023	Bangladesh	Deterministic compartmental modeling for lifestyle interventions	Population-based data from Bangladesh	Lifestyle management intervention and treatment rate	Ordinary differential equations	Lifestyle interventions with 40% effectiveness reduced the diabetic population by 27% and increased the healthy lifestyle population by 29%. Lower effectiveness (10%) saw a 59% increase in susceptible populations, emphasizing intervention quality.	The numerical simulations of the model indicate a notable decrease in the susceptible population class with healthy lifestyle interventions. Enhancing treatment facilities will also lead to significant reduction in the affected population class
Albalawi et al[50]	2023	n/a	Fractional-order modeling for lifestyle changes	Population-based theoretical data	Healthy lifestyle	Fractional order derivative	Higher remission parameters (eg, increased adherence to healthy lifestyles) reduced diabetic populations by up to 29%, while fractional derivatives accelerated reductions compared to integer-order models. The approach demonstrated rapid convergence towards healthier population states.	The analysis of the fractional-order model involving obesity focuses on assessing the impact of a healthy lifestyle on remission, incorporating two additional parameters.

(*Continued*)

Table 2 (Continued).

Author	Years	Location	Type of Study and Methodology	Type of Data Used in Analysis	Type of Intervention	Mathematic Model	Quantitative Findings	Results
Alareeki et al[51]	2023	Qatar	Deterministic modeling for T2DM risk factors	Data from the 2012 STEPwise survey	Interventions include lifestyle management, promoting active commuting, enhancing consumption of fruits and vegetables, introducing subsidies and legislation, and implementing combinations of these approaches	Ordinary differential equations	Reducing obesity by 50% decreased T2DM prevalence by 7.8%–33.7% by 2050 and averted 26,930 cases (38.9%). Smoking reductions were less impactful, averting only 2184 cases (3.2%), while physical inactivity reductions contributed to 7.9% fewer cases.	Conceptual framework of adopting public health approach to address T2DM epidemic, aiming to enhance the quality, effectiveness and cost-effectiveness of multipronged health interventions
Omwenga et al[52]	2023	n/a	SDM with SDEs for glucose-insulin dynamics	Data from a single CGM-monitored patient	Measuring of carbohydrates taken, intensity of physical exercises, and stress levels	Extended Bergman's minimal model	Dietary and stress interventions reduced plasma glucose levels by up to 14.75%, with an average glucose level of 7.86 mmol/L. Exercise intensity showed minimal improvements, highlighting the significant role of diet and stress management.	The study aims to broaden understanding of how carbohydrates, exercise and stress influence changes in blood glucose level among T2DM patients. It also seeks to provide insight into selecting optimal combined intervention for effectively managing blood glucose level.

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The interventions modelled encompass dietary optimizations, lifestyle modifications, awareness campaigns, treatment regimens, and policy measures like subsidies and taxation, addressing both individual and systemic factors. These interventions are modelled using specific mathematical frameworks, including compartmental models, stochastic equations, and optimization algorithms, which align with the scope and goals of the studies. Quantitative findings demonstrate the efficacy of these approaches, with significant reductions in diabetes prevalence and complications observed through integrated strategies. For instance, combined interventions in Qatar reduced diabetes prevalence by up to 46%, while dietary adjustments showed notable impacts on glucose levels in controlled settings.

Discussion

The collective findings from these studies highlight the significant role of mathematical modelling in enhancing diabetes management interventions, particularly for type 2 diabetes mellitus (T2DM). Mathematical models provide a robust framework for designing effective interventions, informing policy decisions, personalising treatment plans, and understanding the underlying disease dynamics. For instance, optimisation and simulation models allow researchers to craft interventions that are both feasible and impactful, particularly when applied in the context of dietary optimisation. As demonstrated by Paidipati et al (2021), these models can minimise glycaemic load while ensuring culturally relevant and nutritionally adequate meal plans. Moreover, by incorporating patient-specific data, such as dietary preferences or restrictions, models can be personalised to improve patient adherence and outcomes.[47]

In addition to dietary interventions, lifestyle changes such as increased physical activity have been modelled using differential equations and fractional-order models, as noted by Ferdous et al (2023) and Albalawi et al (2023). These models provided predictive insights into the influence of lifestyle modifications on the progression and potential remission of T2DM.[46,49,50] Importantly, sensitivity analysis helps to identify the most influential factors, thus allowing targeted interventions that can be tailored to specific patient needs.[50] However, challenges remain in accounting for the socioeconomic factors that shape lifestyle choices, making the development of individualised models that consider patient-specific data even more crucial.[46,49,50] Additionally, there is a critical gap in the representation of holistic and lifestyle-based interventions. For example, keywords such as "exercise" appeared infrequently in the analysed literature, suggesting an underrepresentation of non-pharmacological approaches in current mathematical modelling studies. While pharmacological interventions are widely modelled and supported by robust data, the limited inclusion of non-pharmacological approaches presents a gap that could influence the generalizability of findings, particularly in low- and middle-income countries where access to medications may be restricted.[53]

Awareness of and accessibility to treatment also play a critical role in T2DM management. Mollah and Biswas (2023) emphasised that public knowledge and healthcare services can significantly reduce disease prevalence. Deterministic models help to identify strategies for maximising health benefits while minimising costs, whereas simulation models predict the impact of awareness campaigns and access to treatment over time. Nonetheless, incorporating behavioural economics into these models is necessary to better understand how awareness shapes individual actions, and future efforts should focus on evaluating different types of awareness campaigns to enhance public health outcomes.[48]

At the community level, interventions, such as promoting active commuting and implementing legislative changes, have been shown by Alareeki et al (2023) to reduce T2DM incidence. Deterministic compartmental models are particularly useful for forecasting future disease burdens under different intervention scenarios, whereas sensitivity analysis allows robust policy recommendations to be formulated. A key challenge is to accurately measure the adoption rates of community interventions.[51]

Combining multiple interventions has also been proven beneficial for diabetes management, as demonstrated by Omwenga et al (2023). Stochastic differential equations and system dynamics models capture the complexity of glucose-insulin interactions and variability among individuals, accounting for biological randomness and simulating feedback loops. These models offer insights into the dynamic processes underlying T2DM.[52]

These studies underscore the critical role of mathematical modelling in advancing diabetes management. These models provide insights for designing effective interventions, guide policy decisions, personalise treatment, and understanding disease dynamics. The limitation of the reviewed studies is their reliance on secondary data sources, which may not fully capture the cultural, economic, and demographic diversity of the populations studied. Many models employ theoretical or population-level data, limiting their applicability to real-world scenarios where contextual factors, such as intervention adoption rates and local socio-economic conditions, may significantly influence outcomes.[46,49,50]

These limitations highlight the need for future research to integrate diverse data sources, including clinical outcomes, patient-reported measures, and behavioural insights, into mathematical models. Collaboration between mathematicians, clinicians, and public health experts is essential to ensure that mathematical models are practically applicable in real-world settings.[54,55] Furthermore, involving patients in the modelling process will improve the relevance and acceptance of interventions.[56]

Conclusion

We found seven studies that incorporated interventions into the mathematical models of diabetes mellitus. The studies highlight the critical role of mathematical modelling in understanding and addressing diabetes management across diverse geographic and cultural contexts. Data sources range from India and Bangladesh to Qatar, reflecting varying economic and dietary habits, while some studies use generalized or theoretical data to explore global implications. The interventions modelled include dietary optimization, lifestyle changes, awareness campaigns, treatment, and structural measures such as taxation and subsidies. These models employ diverse mathematical methodologies, including linear optimization, deterministic modelling, fractional-order derivatives, and compartmental models, showcasing their adaptability to different scenarios. The findings underscore the effectiveness of these interventions, with significant reductions in diabetes prevalence achieved through personalized and systemic approaches. For instance, dietary changes and obesity reduction emerged as highly impactful strategies, while combined interventions showed even greater potential. These results demonstrate the value of mathematical models in evaluating and designing targeted interventions to mitigate the burden of diabetes across various regions and populations.

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Disclosure

The authors declare no potential conflicts of interest regarding the research, authorship, or publication of this manuscript.

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