

Review

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Posted Date: 11 November 2025

doi: 10.20944/preprints202511.0789.v1

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Review

Personalized Medicine in the Management of Diabetes: Progress and Gaps

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Abstract

Diabetes is a widespread and growing global health concern, particularly in low- and middle-income countries. Standardized treatment protocols have shown limitations in addressing the complex needs of individuals living with the condition, reinforcing the need for more tailored therapeutic approaches. In contrast, personalized medicine presents significant potential to improve diagnostic and treatment efficiency by considering patients' individual characteristics. To evaluate the applicability and impact of personalized medicine in diabetes management, a literature review was conducted using the Web of Science, Scopus, and PubMed electronic databases. Analysis of the selected studies revealed that patients treated with personalized strategies demonstrated better glycemic control, greater treatment adherence, and a lower incidence of complications. Moreover, studies indicate a reduction in long-term costs due to fewer hospitalizations and adverse events. Personalized medicine emerges as a promising alternative to overcome the limitations of the conventional approach in diabetes treatment. Despite implementation challenges such as costs, technological infrastructure, and professional training, the clinical and economic benefits suggest that this approach is likely to become increasingly consolidated in the coming years.

Keywords: patient stratification; diabetes treatment; precision medicine; individualized medicine; diabetes mellitus

Categories: Family/General Practice, Endocrinology/Diabetes/Metabolism, Healthcare Technology

Introduction And Background

Diabetes is recognized as a global epidemic and stands as one of the most serious public health issues worldwide. It is also among the leading causes of mortality from non-communicable chronic diseases [1–3]. The disease is estimated to be responsible for an average of 1.6 million deaths per year. In 2019 alone, diabetes caused approximately 1.5 million deaths globally [3].

Diabetes is currently advancing at a rapid pace and has reached historic proportions within the global population. It is estimated that around 422 million people are living with the disease, the majority of whom reside in low- and middle-income countries, where access to diagnosis and treatment is more limited [2,4]. However, more recent data from the International Diabetes Federation (IDF), published in the 2019 edition of the Diabetes Atlas, report an even more alarming figure: approximately 463 million adults are living with diabetes worldwide [4]. Furthermore, global and regional estimates indicate that about 50.1% of these individuals are unaware that they have the disease [4], highlighting the severity of underdiagnosis and the urgent need for more effective screening and prevention strategies.

Projections indicate a continuous and concerning increase in the prevalence of diabetes in the coming decades. According to the IDF, the number of adults with the disease is expected to reach 578 million by 2030 and surpass 700 million by 2045 [4,5]. Although some estimates vary such as that of

[1], which predicts approximately 570.9 million people living with diabetes as early as 2025, there is a consensus that the disease will continue to grow significantly.

In the national context, Brazil presents an equally alarming scenario: approximately 16.8 million Brazilians are living with diabetes, and it is estimated that half of these individuals have not yet been diagnosed [4,6]. With these numbers, the country ranks fifth in the world in terms of diabetes prevalence, highlighting the urgent need for more effective public policies focused on early diagnosis, prevention, and treatment.

Given the significant rise in diabetes cases, it becomes clear that traditional medicine, despite considerable advances in diagnosis and treatment, still faces important limitations in effectively managing the disease. One of the main challenges of the conventional approach, based on standardized protocols and average population-based evidence is the low effectiveness of treatments in certain patient groups. Many individuals do not respond adequately to standard therapies, highlighting the need for more personalized approaches that take into account the biological and clinical particularities of each patient.

Considering the risks associated with the “one-size-fits-all” approach, the high rate of ineffectiveness of conventional treatments for type 2 diabetes (T2D), the significant individual variations in therapeutic response, and the substantial costs resulting from complications for healthcare systems, it becomes essential to identify and understand the main personalized medicine models applied to the management of the disease [31].

Therefore, this literature review has two central objectives: (i) to identify the main models and approaches of personalized medicine aimed at the treatment of type 2 diabetes; and (ii) to critically analyze the studies found, with an emphasis on the strategies adopted, in order to contribute to the advancement of knowledge and its application in public health.

Background

The traditional treatment of diabetes is largely based on the “one-size-fits-all” principle, which assumes that all patients with the same clinical condition will respond similarly to a standardized therapeutic intervention. However, this approach overlooks genetic, metabolic, behavioral, and environmental differences among individuals, which compromises the effectiveness of treatments for a significant portion of the population. As a result, high rates of therapeutic inefficiency, estimated at approximately 40% among diabetes patients are observed, posing health risks to patients and substantial financial burdens on healthcare systems [7–9].

In traditional clinical practice, treatment is often prescribed based on general guidelines. If the patient shows little improvement, the doctor adjusts the medication or tries a new approach. This trial-and-error cycle continues until a satisfactory response is found. However, this reactive model based on observing the clinical response after intervention, can lead to negative outcomes. According to [8], it contributes to ineffective results, increased costs, inefficient use of healthcare resources, and avoidable side effects. This highlights the need for more precise and proactive approaches, such as personalized medicine, which aims to anticipate treatment response based on individual characteristics.

This clinical practice model also applies to the main treatments used in diabetes management. While some patients respond well to prescribed therapies, others show limited or no improvement, and a significant portion experience adverse side effects due to inappropriate interventions [9–12]. This variability in therapeutic response highlights a critical limitation of standardized protocols. As noted by [13,14], the use of non-personalized treatments exposes patients to significant risks, such as increased incidence of hyperglycemic events, metabolic complications, and a higher likelihood of hospitalization, ultimately compromising the safety and effectiveness of healthcare delivery.

Given the limitations of traditional approaches, more personalized strategies, considering not only clinical data but also lifestyle, diet, genetics, family history, and environmental factors, are expected to lead to better outcomes. This approach enables earlier diagnosis and treatments tailored to each patient’s needs. According to [12]–[15], customizing diabetes care based on genetic

information can improve treatment effectiveness, reduce therapy failures, and lower the risk of complications. Personalization thus represents a promising step toward safer and more effective diabetes management.

Review

Materials & Methods

This study uses the scientific literature review method to gather, organize, and critically assess available evidence on a research topic following a structured protocol. According to [16,17], literature reviews help identify, select, and synthesize relevant studies to answer specific questions [18]. In healthcare, literature reviews are essential for evaluating emerging clinical practices like personalized medicine.

Personalized medicine is a recent paradigm shift in medical practice, especially in diabetes treatment. This review aims to identify scientific advances, research gaps, and practical applications of personalized medicine in diabetes care. To contextualize this work, Table 1 summarizes key existing reviews, highlighting the number of articles analyzed, the covered period, and each study's focus.

Table 1. Previous reviews on personalized medicine in diabetes.

Literature Review	Review Period	Number of Articles Reviewed	Main Focus
[14]	2009–2015	83 (based on references)	Opportunities and challenges of personalized medicine in type 2 diabetes
[19]	2000–2018	76	Advances in personalized medicine for diagnosis and treatment of type 2 diabetes
[18]	2016–04/2020	92	Trends in AI and modeling applied to personalized medicine for diabetes

The main contribution of this study is to update and expand understanding of personalized medicine application in diabetes treatment, with an emphasis on patient stratification models. This approach supports future research and evidence-based clinical decisions. The research questions (RQs) were formulated following the guidelines of [20] to guide the review and structure the data analysis. They focus on three areas: intervention/methodology, outcomes, and context. The RQs are presented in Table 2.

Table 2. Research Questions (RQs).

Code	Research Questions
RQ1	What limitations of traditional diabetes treatments justify the adoption of personalized medicine?
RQ2	How does the clinical and genetic heterogeneity of type 2 diabetes support the application of personalized medicine?
RQ3	What models, approaches, and criteria have been used to stratify diabetes patients in personalized medicine?
RQ4	What are the main research opportunities in personalized medicine for diabetes?

The search was conducted in three databases recognized for their scientific relevance in health: PubMed, Web of Science, and Scopus. The period analyzed spanned from January 1, 2017, to June 30, 2021, focusing on articles published in English. The search terms used were: "personalized medicine"

OR “individualized medicine” OR “precision medicine” OR “stratified medicine” OR “personalized therapy of diabetes” AND “diabetes.”

This review included full-text articles published in English or Portuguese between January 2017 and June 2021. Eligible studies were those that contained the defined search terms in their titles or abstracts and were published in scientific journals with an impact factor (according to JCR or SJR) greater than 1. Additionally, only articles that explicitly focused on models or applications of personalized medicine for patients with diabetes were considered for inclusion.

Studies were excluded if they were theses, dissertations, conference abstracts, or event proceedings. Articles that were duplicates or lacked full-text access were also excluded. Furthermore, publications that were not directly related to diabetes or that addressed personalized medicine in a generic or non-specific context were not considered in this review.

Results

Diabetes mellitus is widely recognized as a chronic condition with a complex and heterogeneous nature, making it especially suited for the application of personalized medicine principles [21]. This complexity is even more pronounced in type 2 diabetes, whose clinical manifestation results from a multifactorial interaction between genetic predisposition, environmental factors, lifestyle, and diverse pathophysiological mechanisms [11,21]. This patient variability challenges the use of standardized therapeutic approaches, highlighting the need for individualized strategies that consider each person’s genetic, clinical, and metabolic profile for more effective disease management.

Diabetes is a multifaceted and multifactorial condition, whose complexity goes beyond isolated factors such as lifestyle or genetic predisposition [14,22]. Moreover, it is a notably heterogeneous disease, characterized by wide variability in clinical manifestations, genetic profiles, and pathogenic mechanisms among individuals [10], [11,12,14,21,23,24]. This diversity means that patients diagnosed with the same clinical classification of diabetes can, in practice, have different disease trajectories and respond differently to therapeutic interventions. This scenario underscores the need for personalized approaches that consider these individual variations in diagnosis and treatment.

Due to the intrinsic complexity of diabetes, with its multiple causes, diverse clinical manifestations, and genetic variations, treatments based on traditional and generalized clinical practices face serious limitations in terms of effectiveness. However, this limitation reveals a significant opportunity for applying personalized medicine in the context of diabetes [9,10,12,21,23,24]. Although substantial variations among diabetic patients are widely recognized, clinical practice still tends to adopt a standardized approach, treating individuals with distinct metabolic profiles in the same way. This uniformity overlooks individual factors that can directly influence clinical outcomes and treatment responses, contributing to suboptimal results and a higher risk of complications.

Diabetes is a major chronic disease affecting about 463 million people worldwide and a leading cause of morbidity and mortality. Traditional “one-size-fits-all” treatment has limitations, with many patients failing to achieve glycemic targets despite following standard protocols. This highlights the need for more personalized interventions. Personalized medicine offers a promising alternative by optimizing diagnosis and treatment based on individual factors such as genetics, lifestyle, and medical history.

Diabetes mellitus is mainly classified as type 1 and type 2, with type 2 being the most common. Its complexity arises from heterogeneity involving genetic and environmental factors. About 40% of type 2 patients do not respond well to traditional treatments, leading to complications like cardiovascular disease and neuropathies.

Personalized medicine aims to stratify patients by individual traits, offering more effective treatments and fewer side effects. According to [25], it focuses on (i) patient-centered care and (ii) stratification by biological and genetic profiles. Advances in genomics, metabolomics, and artificial intelligence have driven personalized diabetes care, improving clinical outcome predictions.

Contributions include forecasting patient triage and emergency arrivals, optimizing resources, reducing wait times, and enhancing care quality [26–28,31].

Various approaches in personalized diabetes medicine include pharmacogenomics, tailoring drugs to genetic profiles; continuous glucose monitoring using sensors and algorithms to predict glucose changes; and stratified patient classification to group similar patients for optimized treatment.

Challenges remain, such as high costs, data integration, and professional training needs. However, evidence suggests personalized medicine can reduce long-term costs by lowering complications and hospitalizations. Its implementation also requires public policies and regulatory guidelines to ensure accessibility and standardization.

Recent studies highlight that patient stratification using biomarkers can greatly improve treatment effectiveness. Results show personalized approaches lead to better glycemic control and fewer adverse effects. Additionally, personalized medicine can integrate with digital health systems to optimize clinical decisions. Personalized medicine marks a major advance in diabetes care, providing tailored solutions to patient needs. Despite challenges, it is expected to become a key clinical strategy, reducing costs and improving patients' quality of life.

Discussion

Personalized medicine, also known as individualized or precision medicine, refers to an innovative healthcare approach aimed at improving patient stratification and tailoring therapeutic interventions. This approach integrates clinical, genetic, biological, and behavioral information, such as lifestyle, to identify the most suitable prevention, diagnosis, and treatment strategies for each individual. The primary goal of personalized medicine is to maximize therapeutic effectiveness and minimize the risk of adverse effects by adapting interventions to each patient's specific characteristics [8], [10,14,15,25]. This paradigm shift represents an evolution from traditional medicine, which often relies on generalized guidelines that do not account for individual variability.

According to [25], the concept of personalized medicine involves two central pillars: (i) healthcare focused on the specific needs of each individual, promoting a holistic and patient-centered approach; and (ii) the stratification of patients into subgroups with similar biological, clinical, or behavioral characteristics to enable more effective and safer therapies. Although the idea of tailoring treatment to patient specifics dates back to the origins of medical practice, where knowledge of the individual was as important as knowledge of the disease [8,24,25], contemporary personalized medicine relies on technological and scientific advances such as genomics and machine learning. This literature review adopts the latter understanding, emphasizing patient stratification in diabetes mellitus, especially type 2, to explore the most effective models and approaches for personalized treatment.

Personalized medicine gained international prominence particularly in January 2015, when then-President of the United States, Barack Obama, announced the creation of the "Precision Medicine Initiative" during his State of the Union address. This initiative marked a turning point in public health policy by proposing systematic investment in research focused on the personalization of treatments for diseases such as cancer and diabetes, with the goal of significantly improving medical care and the quality of life for American patients [22,24].

However, the concept and foundations of personalized medicine predate this milestone. Since antiquity, medical practices have sought to tailor treatments to individual patient characteristics, albeit empirically. Hippocrates, for instance, acknowledged variations in temperament and environment as key factors in determining treatment. With advances in genetics, especially following the completion of the Human Genome Project in 2003, the integration of molecular, clinical, and environmental information into medical care emerged as a new therapeutic paradigm. This scientific and technological progress enabled the identification of biomarkers, genetic profiles, and personalized risk factors, which are central elements in the contemporary application of personalized medicine [8,10,25].

Thus, Obama's 2015 announcement did not mark the beginning but rather the political and institutional consolidation of a trend that had been evolving for decades—boosting public and private investment, particularly in fields such as oncology, cardiovascular diseases, and type 2 diabetes, where clinical heterogeneity among patients demands more precise and individualized therapeutic strategies.

Despite the significant progress of personalized medicine in diabetes treatment and growing evidence of its benefits in improving therapeutic outcomes [23], the scientific community acknowledges that the field still faces major gaps. Researchers highlight that while current results are promising, further investigations, both basic and applied, are needed to establish personalized medicine as a robust and widely accessible clinical approach for diabetes management [10,13,14,21].

This need arises from the biological complexity of diabetes, individual variability in treatment response, and the demand for technological infrastructure to integrate genomic, phenotypic, and behavioral data.

Moreover, limited large-scale cost-effectiveness evidence highlights the importance of further research exploring not only clinical efficacy but also economic feasibility and equitable access to personalized medicine.

In the context of personalized diabetes therapy, there is strong potential to use individual patient characteristics such as genetic profile, environmental factors, lifestyle, and clinical history to guide more effective and targeted diagnostic and treatment strategies [14,21,24]. Personalized medicine aims to enhance the effectiveness of interventions for complex, multifactorial diseases like diabetes, which exhibit high clinical heterogeneity. Its core objective is to deliver the right treatment or medication, at the right time, to the right patient maximizing therapeutic benefits while minimizing adverse effects [9,12,29].

One of the main goals of personalized medicine for diabetes, as highlighted in the joint consensus report by the American Diabetes Association (ADA) and the European Association for the Study of Diabetes (EASD), is the development of new clinical classifications to simplify and optimize treatment maximizing therapeutic effectiveness while minimizing adverse effects [10,30]. In practice, this involves stratifying diabetic patients into homogeneous subgroups based on similar phenotypic, genetic, and clinical characteristics, as well as patterns of disease progression and treatment response. This segmentation enables more precise selection of the most appropriate therapy for each subgroup, supporting more personalized and effective interventions for managing the disease.

Conclusions

Personalized medicine represents a promising shift in the management of diabetes, offering the potential for more tailored and effective treatment strategies. By identifying subgroups of patients with similar characteristics, this approach can lead to more precise interventions and better clinical outcomes.

Implementing such strategies may also improve the efficiency of healthcare delivery by reducing trial-and-error in treatment selection.

Despite recent progress, challenges remain in translating personalized medicine into routine clinical practice. Continued efforts are needed to develop robust classification models, integrate emerging AI technologies, and ensure that healthcare systems are prepared to support these innovations. Collaboration across disciplines, investment in professional training, and alignment with health policy will be key to realizing the full benefits of this approach. Future studies should focus on large-scale implementation and cost-effectiveness in healthcare systems.

Conflicts of interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following:

Payment/services info: All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in

the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.:

Acknowledgments: This work was funded by the National Council for Scientific and Technological Development (CNPq), Brazil, through the GD doctoral scholarship [141150/2021-1].

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