

Modern methods of diagnostics and treatment of the cardiovascular system

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Abstract. Type 2 diabetes mellitus (T2DM) is a chronic metabolic disorder characterized by insulin resistance, progressive β -cell dysfunction, and hyperglycemia. Despite the availability of various pharmacological agents, many patients fail to achieve long-term glycemic control, highlighting the need for more effective and personalized treatment strategies. Recent advances in biomedical research have led to the development of innovative therapies targeting the molecular and genetic underpinnings of the disease. This paper explores the latest developments in the treatment of T2DM, focusing on cutting-edge approaches such as gene therapy, peptide-based drugs, incretin mimetics, SGLT2 inhibitors, and dual or triple agonists targeting multiple metabolic pathways. Gene editing techniques like CRISPR/Cas9 offer the potential to correct genetic predispositions and enhance insulin sensitivity or pancreatic function. Additionally, novel drugs aimed at modulating gut microbiota and inflammatory responses are showing promising results in both preclinical and clinical trials.

1 Introduction

Type 2 diabetes mellitus (T2DM) is a prevalent and progressive metabolic disorder that affects more than 500 million people worldwide. Characterized by insulin resistance, impaired insulin secretion, and chronic hyperglycemia, T2DM is associated with numerous complications, including cardiovascular disease, nephropathy, neuropathy, and retinopathy. Despite the availability of a broad range of pharmacological treatments—such as metformin, sulfonylureas, DPP-4 inhibitors, and insulin—many patients continue to experience suboptimal glycemic control, adverse drug reactions, and disease progression.

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This underscores the urgent need for more effective, durable, and individualized therapeutic strategies.

In recent years, remarkable advances in molecular biology, genetics, and biotechnology have revolutionized the landscape of diabetes treatment. Researchers are now exploring novel therapeutic avenues that go beyond symptomatic control to address the root causes of metabolic dysfunction. Gene therapy, RNA-based technologies, incretin receptor agonists, dual- and triple-hormone co-agonists, SGLT2 inhibitors, and targeted anti-inflammatory agents are among the most promising innovations under investigation. Additionally, the application of CRISPR/Cas9 gene editing and personalized medicine approaches offers the potential for disease modification and even long-term remission in selected patients.

This paper aims to review the current state of innovative therapies for T2DM, with a focus on gene-based strategies, advanced pharmacological compounds, and integrated treatment models that combine metabolic, genetic, and lifestyle interventions. By examining both preclinical research and clinical trial data, the discussion will highlight the therapeutic potential, limitations, and future directions of these emerging approaches.

2 Methods and materials

The review of recent scientific literature and clinical trial data reveals significant progress in the development of innovative therapies for type 2 diabetes mellitus (T2DM). These advancements span across several domains, including gene-based interventions, novel pharmacological agents, and combination therapies targeting multiple metabolic pathways. One of the most promising areas is gene therapy and RNA-based approaches. Preclinical studies using viral vectors and CRISPR/Cas9 gene-editing technology have shown potential in restoring insulin production, enhancing β -cell survival, and improving insulin sensitivity in animal models. Specifically, targeting genes involved in glucose transport (such as GLUT4), insulin signaling (e.g., IRS-1, AKT), and β -cell regeneration has yielded encouraging results. In addition, mRNA therapies are being explored to temporarily express therapeutic proteins involved in glycemic control without permanent genome modification. In the field of pharmacological innovation, newer classes of drugs have demonstrated substantial clinical efficacy. Sodium-glucose co-transporter 2 (SGLT2) inhibitors, such as empagliflozin and dapagliflozin, not only lower blood glucose but also improve cardiovascular and renal outcomes. Similarly, glucagon-like peptide-1 receptor agonists (GLP-1 RAs) and dual/triple agonists (e.g., GLP-1/GIP/glucagon co-agonists) are proving effective in promoting weight loss, enhancing insulin secretion, and reducing postprandial glucose levels. Several anti-inflammatory and gut microbiota-modulating therapies are also emerging. Chronic low-grade inflammation is increasingly recognized as a key contributor to insulin resistance. Novel agents targeting interleukins (e.g., IL-1 β inhibitors) or Toll-like receptors have shown promise in early-phase trials. In parallel, microbiome-based treatments—including probiotics, prebiotics, and fecal microbiota transplantation—are being investigated for their ability to improve glucose metabolism by altering gut microbial composition. In addition, personalized medicine approaches that integrate genetic profiling, lifestyle data, and pharmacogenomics are gaining traction. Pilot programs using AI-based treatment algorithms have improved individual responses to therapies and minimized side effects by tailoring drug selection and dosage to a patient's unique metabolic profile. Overall, the results indicate a paradigm shift in T2DM management—from generalized glycemic control to mechanism-specific and patient-tailored therapies. While many of these innovations are still in the experimental or early

clinical stages, they represent a major step forward in addressing the underlying causes of the disease and improving long-term patient outcomes.

3. Results

The emerging landscape of innovative treatments for type 2 diabetes mellitus (T2DM) represents a paradigm shift from traditional symptom-focused therapies toward mechanism-based, precision medicine approaches. Historically, management of T2DM relied heavily on lifestyle modification and pharmacological agents aimed primarily at lowering blood glucose levels, such as metformin, sulfonylureas, and insulin. While these treatments mitigate hyperglycemia, they often do not halt or reverse the progressive decline in pancreatic β -cell function nor address the underlying pathophysiology of insulin resistance and chronic systemic inflammation.

Recent advances in molecular biology, genetics, and pharmacology have uncovered key pathological drivers of T2DM, enabling the development of targeted therapies that address the disease at its roots. Among these drivers are insulin resistance, characterized by impaired cellular response to insulin in muscle, fat, and liver tissue; β -cell dysfunction, leading to insufficient insulin secretion; and chronic low-grade inflammation, which exacerbates both metabolic dysregulation and tissue damage.

Gene Therapy and Gene Editing Technologies

One of the most promising frontiers in T2DM treatment is gene therapy, including gene-editing techniques such as CRISPR/Cas9, which allow for precise modification of DNA sequences involved in glucose metabolism and insulin regulation. Preclinical studies have demonstrated the potential of gene-editing to restore insulin production by correcting mutations in genes like *PDX1* and *HNF1A*, which are critical for pancreatic development and function (Wang et al., 2021). Additionally, CRISPR-based approaches targeting genes associated with insulin resistance—such as *IRS1* and *AKT2*—have shown improved insulin signaling in animal models (Lee et al., 2022).

However, the transition from bench to bedside faces several challenges. Efficient and safe delivery systems remain a major hurdle, as viral vectors and nanoparticle carriers must target pancreatic tissue specifically without triggering immune reactions or off-target genome edits. Long-term safety and efficacy data are still limited, with concerns about potential oncogenesis or unintended genetic modifications (Smith et al., 2020). Ethical debates surrounding germline editing and equitable access to these therapies further complicate their clinical deployment.

Novel Pharmacotherapies

Alongside gene-based interventions, novel pharmacological agents have transformed T2DM management. Sodium-glucose co-transporter 2 (SGLT2) inhibitors, such as empagliflozin and dapagliflozin, not only lower blood glucose by promoting renal glucose excretion but also reduce cardiovascular morbidity and mortality, as demonstrated in the EMPA-REG OUTCOME trial (Zinman et al., 2015). Furthermore, glucagon-like peptide-1 receptor agonists (GLP-1 RAs), including liraglutide and semaglutide, enhance insulin secretion, suppress glucagon release, delay gastric emptying, and induce weight loss, with added cardiovascular benefits (Marso et al., 2016).

More recently, dual and triple agonists targeting multiple incretin pathways—such as GLP-1/GIP co-agonists (tirzepatide)—have shown superior glycemic control and weight reduction compared to single agonists (Frias et al., 2018). These multi-target agents capitalize on the synergistic effects of hormonal pathways to address complex metabolic derangements.

Despite these benefits, concerns about high costs and variable insurance coverage limit patient access, especially in low- and middle-income countries. Additionally, long-term safety data beyond 5–10 years remain sparse, warranting ongoing pharmacovigilance.

Anti-Inflammatory and Gut Microbiota-Targeted Therapies

Increasing evidence implicates chronic low-grade inflammation in the pathogenesis of insulin resistance and β -cell failure. Pro-inflammatory cytokines such as IL-1 β , TNF- α , and IL-6 interfere with insulin signaling and promote metabolic dysfunction (Donath & Shoelson, 2011). Targeting these inflammatory mediators with agents like canakinumab (an IL-1 β inhibitor) has yielded promising results in reducing systemic inflammation and improving glycemic control in pilot clinical trials (Ridker et al., 2017).

Simultaneously, the role of the gut microbiota in T2DM has attracted substantial interest. Dysbiosis—an imbalance in gut microbial composition—has been linked to increased intestinal permeability, systemic inflammation, and altered metabolism (Qin et al., 2012). Interventions such as probiotics, prebiotics, and fecal microbiota transplantation (FMT) are under investigation for their potential to restore eubiosis and improve insulin sensitivity. Early-phase trials have reported improvements in metabolic markers and inflammatory profiles following these therapies (Zhang et al., 2019), although standardized protocols and long-term efficacy data remain lacking.

Personalized medicine approaches integrate genetic, metabolic, and lifestyle data to tailor therapies to individual patient profiles. Pharmacogenomic studies have identified genetic variants influencing drug metabolism and response, enabling optimization of medication regimens (Florez, 2017). Furthermore, machine learning and artificial intelligence (AI) algorithms analyze large datasets to predict treatment responses and risk profiles, facilitating proactive and adaptive management plans.

For example, AI-driven platforms can integrate continuous glucose monitoring (CGM) data with lifestyle inputs to suggest personalized insulin dosing or dietary adjustments (Contreras & Vehi, 2018). Such precision approaches hold promise to maximize therapeutic efficacy, minimize adverse effects, and enhance patient adherence.

However, widespread adoption faces barriers including the need for robust, interoperable data infrastructures, protection of patient privacy, and addressing disparities in digital health literacy.

In summary, while innovative treatments for T2DM carry transformative potential, their successful clinical integration depends on overcoming scientific challenges such as delivery and safety of gene therapies, ensuring equitable access to novel pharmacotherapies, standardizing anti-inflammatory and microbiota-targeted interventions, and establishing frameworks for personalized medicine incorporating AI. Multidisciplinary collaboration among researchers, clinicians, regulatory bodies, and patient advocacy groups is essential to translate these breakthroughs into real-world benefits.

Further large-scale clinical trials and longitudinal studies will be critical to validate these emerging therapies' efficacy, safety, and cost-effectiveness. Additionally, addressing ethical, social, and economic factors will be paramount to ensure these innovations improve outcomes for the global population living with T2DM.

4. Discussion

The emerging landscape of innovative treatments for type 2 diabetes mellitus (T2DM) reflects a significant departure from traditional therapeutic paradigms centered primarily on symptom management. Advances in molecular biology, genetics, and pharmacology have opened new avenues for interventions that target the fundamental pathophysiological

mechanisms driving T2DM, including insulin resistance, β -cell dysfunction, and chronic inflammation.

Gene therapy and gene-editing technologies, particularly those utilizing CRISPR/Cas9, offer unprecedented opportunities for precise correction of genetic abnormalities contributing to impaired glucose metabolism. While preclinical data are promising, challenges such as efficient and safe delivery systems, off-target effects, and long-term safety remain to be fully addressed before widespread clinical application can be realized. Moreover, ethical considerations surrounding gene editing require careful deliberation within the broader medical community.

The rapid expansion of novel pharmacotherapies—such as SGLT2 inhibitors, GLP-1 receptor agonists, and multi-agonist drugs—demonstrates considerable benefits beyond glycemic control, including cardiovascular and renal protection, weight reduction, and improved patient adherence due to favorable side effect profiles. However, issues related to cost, accessibility, and long-term safety data pose challenges for equitable and sustainable implementation, especially in low-resource settings.

Anti-inflammatory and gut microbiota-targeted therapies represent an exciting frontier in T2DM treatment, underscoring the complex interplay between metabolic dysfunction and immune responses. Though still in early stages, these approaches may complement existing treatments by addressing underlying systemic inflammation and metabolic dysbiosis. Future research is required to clarify optimal candidates for such therapies and to standardize treatment protocols.

Personalized medicine approaches, leveraging genetic and metabolic profiling combined with artificial intelligence, promise to enhance therapeutic efficacy by tailoring interventions to individual patient characteristics. Such strategies could minimize adverse effects and optimize clinical outcomes, but they also demand robust data infrastructure and raise concerns about patient privacy and data security.

In summary, while innovative treatments for T2DM hold transformative potential, their successful integration into clinical practice hinges on overcoming scientific, ethical, economic, and logistical barriers. Multidisciplinary collaboration among researchers, clinicians, policymakers, and patient communities will be essential to translate these advances into tangible health benefits for the growing population affected by T2DM.

3 Conclusion

The landscape of type 2 diabetes treatment is undergoing a transformative shift fueled by advances in gene therapy, novel pharmacological agents, and personalized medicine. This review highlights the potential of these innovative approaches to address the underlying mechanisms of T2DM, such as insulin resistance, β -cell dysfunction, and chronic inflammation, moving beyond conventional symptom management. Gene-editing technologies like CRISPR/Cas9 and emerging RNA-based therapies offer the prospect of disease modification or even remission, while new drug classes including SGLT2 inhibitors and multi-agonists provide improved efficacy and additional benefits for cardiovascular and renal health. Despite promising developments, challenges remain in terms of safety, delivery methods, cost, and equitable access. Moreover, integrating personalized treatment regimens requires robust data management and ethical considerations surrounding patient privacy. Continued interdisciplinary research and collaboration will be essential to overcome these hurdles and translate these breakthroughs into widely accessible clinical therapies. In conclusion, innovative treatments for T2DM represent a critical step forward in improving patient outcomes and quality of life. The future of diabetes care lies in

combining molecular insights with precision medicine to develop safe, effective, and individualized therapeutic strategies.

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