Diabetes mellitus today: A comprehensive review of epidemiology, mechanisms, diagnostics, technology, and therapeutic futures with implications for Thailand

Jidapha Wannaprabha[1] ,Jarupat Bulpakdi[2],Chakrin Techaboonsermsak[3], Natalie Zannier Porzella[4] ,Korawan Arsa[5], Sujimon Mungkalarungsi[6]
Horwang School[1] Ruamrudee International School[2]
Ramkhamhaeng Advent International School[3]International School Bangkok[4]
Patumwan Demonstration School[5] , Independent Researcher[6]
Email: v.r.vermoth.981@gmail.com[1] , Email: Mightybul2008@gmail.com[2]
Email: Ottopersonal817@gmail.com[3] , Email: 22871@students.isb.ac.th[4]
Email: hellokorawan@gmail.com[5] , E-mail: khunsujimon.m@gmail.com[6]

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ABSTRACT

Diabetes mellitus (DM) is a major and growing global health challenge driven by urbanization, population aging, and lifestyle changes. This study was conducted as a narrative review, synthesizing evidence from major databases and clinical guidelines. A narrative review was conducted using major scientific databases and clinical guidelines. Findings indicate a shift toward predictive, personalized, and technology enabled care, including advances in pharmacological therapies and digital health tools. In Thailand. challenges such as underdiagnosis and unequal access to care highlight the need for strengthened health system integration and improved early detection strategies.

Keywords: Diabetes mellitus, Epidemiology, Pathophysiology, Digital health, Therapeutic advances, Thailand

Introduction

Diabetes mellitus (DM) has emerged as one of the most significant global health challenges of the 21st century, with a rapidly increasing prevalence driven by urbanization, population aging, sedentary lifestyles, and widening socioeconomic disparities (Zimmet et al., 2016). Beyond its growing incidence, diabetes imposes a substantial burden of premature mortality, disability, and escalating healthcare costs through its strong association with cardiovascular disease, chronic kidney disease, neuropathy, retinopathy, and cognitive decline (Fowler, 2008; Beckman et al., 2002; Biessels & Despa, 2018). In Thailand, this burden is further intensified by a rising prevalence of young-onset type 2 diabetes, demographic aging, and limitations within fragmented chronic-care delivery systems that must simultaneously accommodate expanding therapeutic innovations and constrained healthcare resources (Aekplakorn et al., 2019; Dejkhamron et al., 2022; Atun et al., 2017). These challenges highlight the need for context-specific strategies that align scientific advances with the realities of national health systems.

Recent scientific developments have redefined diabetes as a complex, multisystem disorder rather than a condition solely characterized by hyperglycemia. Type 2 diabetes is now understood to involve the interplay of

insulin resistance, progressive β-cell dysfunction, chronic inflammation, and oxidative stress (DeFronzo et al., 2015; Donath & Shoelson, 2011; Kahn et al., 2014), whereas type 1 diabetes is increasingly conceptualized as a staged autoimmune disease that allows opportunities for early detection and intervention (Insel et al., 2015). Therapeutic paradigms have evolved beyond glycemic control alone, with sodium–glucose cotransporter 2 (SGLT2) inhibitors and glucagon-like peptide-1 (GLP-1) receptor agonists demonstrating significant cardiovascular and renal protective effects (Zinman et al., 2015; Marso et al., 2016). In parallel, technological innovations such as continuous glucose monitoring (CGM) have shifted clinical emphasis toward dynamic metrics such as time in range, enhancing real-time disease management (Battelino et al., 2019). Emerging therapies including immunomodulatory approaches such as anti-CD3 agents (Herold et al., 2019), regenerative stem-cell strategies (Pagliuca et al., 2014), and microbiome-targeted interventions (Gurung et al., 2020; Lynch & Pedersen, 2016) further reflect a transition toward predictive, personalized, and technology-enabled care.

Despite these advances, substantial gaps remain in translating innovation into effective, equitable, and scalable healthcare delivery. A significant proportion of individuals with diabetes remain undiagnosed or inadequately treated, particularly in resource-constrained settings (Zimmet et al., 2016). In Thailand, disparities in access to advanced pharmacological therapies, diagnostic tools, and digital health technologies persist, while healthcare systems remain insufficiently integrated to support the continuous, multidisciplinary nature of diabetes management (Atun et al., 2017). Moreover, psychosocial determinants including diabetes-related distress and depression are increasingly recognized as critical factors influencing clinical outcomes but remain under-integrated into routine care (Biessels & Despa, 2018). The rapid expansion of digital health and artificial intelligence (AI) also introduces new challenges related to digital equity, workforce readiness, reimbursement mechanisms, and data governance, necessitating coordinated system-level responses.

Although a growing body of literature has explored pharmacological therapies, digital health, and immunological interventions independently, there remains a lack of comprehensive synthesis that integrates these domains within a unified framework relevant to the Thai healthcare context. Critical uncertainties persist regarding how precision medicine can be translated into sustainable and scalable care models, the real-world effectiveness of technologies such as CGM, telemedicine, and AI-assisted management, and the feasibility of implementing disease-modifying therapies in settings with variable resources and infrastructure. Furthermore, current literature provides limited analysis of how Thailand can strategically adapt these innovations to address its specific epidemiological trends, healthcare system constraints, and policy priorities.

Therefore, this review aims to provide a multidimensional synthesis of contemporary evidence on diabetes mellitus, integrating advances in pathophysiology, diagnosis, therapeutics, and digital health with an emphasis on their implications for Thailand. By bridging biological mechanisms, clinical evidence, technological innovation, and health system considerations, this review seeks to identify strategic priorities for improving diabetes prevention, management, and long-term outcomes within the Thai context.

Purpose of the Study

This review aims to synthesize contemporary evidence on diabetes mellitus across epidemiology, pathophysiology, diagnosis, complications, and emerging therapeutic and technological innovations.

In addition, the review seeks to integrate these domains within a unified framework to examine their implications for diabetes management in Thailand, with the goal of identifying context-specific priorities for improving prevention, care delivery, and long-term outcomes.

Methods

This study was conducted as a narrative review to synthesize contemporary evidence on diabetes mellitus across epidemiology, pathophysiology, diagnosis, complications, therapeutics, digital health, and health system implications, with particular emphasis on relevance to Thailand.

A structured literature search was performed using PubMed/MEDLINE, Scopus, Web of Science, and Google Scholar. Additional sources included clinical guidelines and reports from major organizations, such as the World Health Organization (WHO), International Diabetes Federation (IDF), and the American Diabetes Association (ADA). Search terms included combinations of "diabetes mellitus," "type 1 diabetes," "type 2 diabetes," "diagnosis," "complications," "SGLT2 inhibitors," "GLP-1 receptor agonists," "continuous glucose monitoring," "telemedicine," "artificial intelligence," "immunotherapy," "microbiome," and "stem cell."

Studies published between approximately 2001 and 2024 were considered. Priority was given to peer-reviewed articles, landmark clinical trials, high-impact mechanistic studies, and international consensus guidelines that are relevant to current clinical practice and emerging innovations. Older studies were included selectively when they provided foundational or widely cited evidence.

Articles were screened based on predefined inclusion and exclusion criteria. Inclusion criteria comprised: (1) studies addressing key domains of diabetes care, including mechanisms, diagnosis, complications, therapeutics, digital health, or health system implementation; (2) studies with clear clinical, scientific, or policy relevance; and (3) publications in peer-reviewed journals or recognized institutional reports. Exclusion criteria included: (1) studies lacking relevance to the review objectives; (2) non–peer-reviewed sources, editorials, and opinion-based articles without supporting evidence; and (3) duplicate publications.

The selection process involved initial screening of titles and abstracts, followed by full-text review of potentially relevant articles. Studies were then prioritized based on scientific rigor, relevance to contemporary practice, and contribution to thematic synthesis. From the screened literature, 34 publications were selected as key references because they represented high-quality evidence, landmark findings, or authoritative guidance across the major domains of interest.

Data from selected studies were analyzed using a thematic synthesis approach. Evidence was organized into predefined domains—epidemiology, mechanisms, diagnosis, complications, technology, therapeutic advances, and health system considerations—to provide a structured and integrative overview. As a narrative review, this study did not include quantitative meta-analysis or formal risk-of-bias assessment.

1. Epidemiology and Burden of Disease

1.1 Global Trends

Diabetes mellitus (DM) is a major and growing global health challenge, driven by urbanization, aging populations, and lifestyle changes (Zimmet et al., 2016). Its rising prevalence is accompanied by increased morbidity and mortality due to complications such as cardiovascular disease, chronic kidney disease, neuropathy, and retinopathy, contributing to substantial healthcare and economic burden worldwide (Fowler, 2008; Beckman et al., 2002).

1.2 Epidemiological Situation in Thailand

In Thailand, diabetes prevalence has steadily increased, largely due to rising obesity, sedentary lifestyles, and demographic aging (Aekplakorn et al., 2019). Despite improved detection and treatment, many individuals remain undiagnosed or poorly controlled, leading to preventable complications. Health system challenges, including disparities in access to care and fragmented chronic disease management, further exacerbate the burden (Atun et al., 2017).

1.3 Risk Factors

Diabetes is influenced by modifiable risk factors such as obesity, unhealthy diet, and physical inactivity, alongside non-modifiable factors including age and genetic susceptibility. In Thailand, rapid urbanization and dietary transitions have intensified exposure to these risks, emphasizing the need for effective prevention strategies (Aekplakorn et al., 2019).

1.4 Young-Onset Diabetes

Young-onset type 2 diabetes is increasingly observed in Thailand, particularly among adolescents and young adults. This group often presents with poorer glycemic control and earlier complications compared to later-onset cases (Dejkhamron et al., 2022). The trend reflects early exposure to metabolic risk factors and poses significant long-term challenges for the healthcare system.

2. Pathophysiological Mechanisms

Diabetes mellitus comprises a heterogeneous group of disorders characterized by dysregulated glucose homeostasis resulting from defects in insulin secretion, insulin action, or both. Type 1 diabetes (T1D) is an autoimmune condition marked by T cell–mediated destruction of pancreatic β-cells, leading to absolute insulin deficiency. It is increasingly recognized as a staged disease, allowing for earlier identification and potential intervention during presymptomatic phases (Insel et al., 2015). In contrast, type 2 diabetes (T2D) is primarily driven by insulin resistance in peripheral tissues combined with progressive β-cell dysfunction, resulting in relative insulin deficiency (DeFronzo et al., 2015; Kahn et al., 2014).

Chronic low-grade inflammation plays a central role in the pathogenesis of T2D, linking obesity and metabolic dysfunction to impaired insulin signaling. Adipose tissue inflammation, mediated by pro-inflammatory cytokines and immune cell infiltration, contributes to systemic insulin resistance and β-cell stress (Donath & Shoelson, 2011). These processes are further exacerbated by oxidative stress and mitochondrial dysfunction, reinforcing a cycle of metabolic dysregulation.

The gut microbiome has emerged as an important modulator of metabolic health, influencing glucose metabolism, immune responses, and energy balance. Dysbiosis in individuals with T2D is associated with reduced production of beneficial metabolites such as short-chain fatty acids and increased systemic inflammation (Gurung et al., 2020; Lynch & Pedersen, 2016). Although the microbiome represents a promising therapeutic target, its clinical application remains under active investigation.

3. Diagnosis and Classification

The diagnosis of diabetes mellitus is based on standardized biochemical criteria associated with long-term complications, including glycated hemoglobin (HbA1c) ≥ 6.5%, fasting plasma glucose ≥ 126 mg/dL, 2-hour plasma glucose ≥ 200 mg/dL during an oral glucose tolerance test, or random plasma glucose ≥ 200 mg/dL in the presence of classic symptoms (ADAPPC, 2025). These criteria remain fundamental to clinical practice; however, contemporary approaches increasingly emphasize early detection and risk stratification.

Beyond conventional classification, precision-based approaches have gained importance in differentiating diabetes subtypes and guiding individualized management. Type 1 diabetes is

characterized by autoimmune β-cell destruction and can be identified through autoantibody testing and staging frameworks (Insel et al., 2015), while type 2 diabetes involves heterogeneous metabolic dysfunction influenced by genetic and environmental factors (DeFronzo et al., 2015; Kahn et al., 2014). Recognition of atypical forms, such as latent autoimmune diabetes in adults (LADA) and monogenic diabetes, further underscores the need for accurate classification to optimize therapeutic decisions.

In Thailand, challenges in diabetes screening and diagnosis persist, particularly in relation to underdiagnosis and delayed detection. A substantial proportion of individuals with diabetes remain unaware of their condition, and many do not achieve adequate treatment or glycemic control. Additionally, approximately one-third of diabetes cases remain undiagnosed, reflecting gaps in early detection and screening coverage (International Diabetes Federation, 2024). Limitations in screening program effectiveness, variability in healthcare access, and reliance on opportunistic testing further contribute to incomplete detection and delayed management (Mahikul et al., 2019). Strengthening population-based screening, improving risk stratification, and integrating diagnostic pathways within primary care systems are therefore critical for reducing complications and improving long-term outcomes.

4. Complications and Clinical Consequences

Diabetes mellitus is associated with a wide spectrum of complications that significantly contribute to morbidity, mortality, and healthcare burden. These complications arise primarily from chronic hyperglycemia and metabolic dysregulation, affecting both microvascular and macrovascular systems, as well as other organ functions (Fowler, 2008; Brownlee, 2005).

4.1 Microvascular Complications

Microvascular complications include diabetic retinopathy, nephropathy, and neuropathy, which are major causes of blindness, end-stage renal disease, and disability, respectively. Persistent hyperglycemia induces oxidative stress, endothelial dysfunction, and microvascular damage, leading to progressive tissue injury (Brownlee, 2005). Tight glycemic and blood pressure control have been shown to reduce the risk and progression of these complications (UKPDS, 1998).

4.2 Macrovascular Complications

Macrovascular complications, particularly atherosclerotic cardiovascular disease (ASCVD), represent the leading cause of death among individuals with diabetes (Kannel & McGee, 1979). Pathophysiological mechanisms include endothelial dysfunction, chronic inflammation, and dyslipidemia, which accelerate atherogenesis (Beckman et al., 2002). Recent therapeutic advances, such as SGLT2 inhibitors and GLP-1 receptor agonists, have demonstrated significant cardiovascular benefits, shifting treatment priorities toward comprehensive cardiometabolic risk reduction (Zinman et al., 2015; Marso et al., 2016).

4.3 Cognitive and Other Complications

Beyond vascular complications, diabetes is increasingly recognized as a risk factor for cognitive decline and dementia. Mechanisms include insulin resistance in the brain, microvascular injury, and chronic inflammation (Biessels & Despa, 2018; Craft, 2005). Additional complications, such as diabetic foot disease, arise from the interplay of neuropathy, vascular insufficiency, and infection, leading to increased risk of hospitalization and amputation (Schaper et al., 2020). These diverse clinical consequences highlight the need for integrated, multidisciplinary management strategies to reduce long-term disease burden.

5. Technology and Digital Health

Advances in digital health technologies are transforming diabetes management by enabling continuous

monitoring, personalized care, and improved access to healthcare services. These innovations address key challenges in chronic disease management, including fragmented care and limited specialist availability (Salisbury et al., 2015; Atun et al., 2017).

5.1 Continuous Glucose Monitoring (CGM)

Continuous glucose monitoring (CGM) has shifted diabetes management from static measures such as glycated hemoglobin (HbA1c) to dynamic metrics, including time in range (TIR), which better reflect daily glycemic variability (Battelino et al., 2019). CGM enhances detection of hypoglycemia, supports treatment optimization, and improves patient engagement, particularly in individuals with type 1 diabetes and insulin-treated type 2 diabetes.

5.2 Telemedicine

Telemedicine enables remote delivery of diabetes care through virtual consultations, digital communication, and remote patient monitoring. Evidence suggests that telehealth interventions can achieve glycemic outcomes comparable to in-person care while improving accessibility and continuity, especially in resource-limited settings (Salisbury et al., 2015). These approaches are particularly valuable for expanding care coverage and supporting long-term disease management.

5.3 Artificial Intelligence (AI)

Artificial intelligence (AI) is increasingly applied in diabetes care for predictive analytics, clinical decision support, and complication screening. AI-based systems have demonstrated high accuracy in detecting diabetic retinopathy and in predicting risks such as hypoglycemia and disease progression (Gulshan et al., 2016; Beckman et al., 2002). Despite its potential, implementation challenges remain, including data governance, algorithm bias, and integration into clinical workflows, particularly in settings with limited digital infrastructure (Atun et al., 2017).

6. Therapeutic Advances and Future Directions

Recent advances in diabetes therapeutics have shifted management beyond glycemic control toward comprehensive cardiometabolic risk reduction and disease modification. These developments reflect a broader transition toward precision and mechanism-based treatment strategies.

6.1 SGLT2 Inhibitors and GLP-1 Receptor Agonists

Sodium glucose cotransporter 2 (SGLT2) inhibitors and glucagon-like peptide-1 (GLP-1) receptor agonists have transformed the management of type 2 diabetes by providing benefits that extend beyond glucose lowering. Large-scale clinical trials have demonstrated significant reductions in cardiovascular events, heart failure hospitalization, and progression of chronic kidney disease (Zinman et al., 2015; Marso et al., 2016; Perkovic et al., 2019). These agents are now central to treatment guidelines, reflecting a paradigm shift toward integrated cardiometabolic risk management.

6.2 Immunotherapy

In type 1 diabetes, immunotherapy represents a promising approach aimed at modifying disease progression rather than solely replacing insulin. Monoclonal antibodies such as anti-CD3 agents have shown the ability to delay the onset of clinical disease in high-risk individuals by preserving residual β-cell function (Herold et al., 2019). Other immunomodulatory therapies, including agents targeting T-cell activation, have demonstrated varying degrees of efficacy in early-stage disease (Orban et al., 2014; Rigby et al., 2015). Despite these advances, challenges related to long-term efficacy, safety, and cost remain.

6.3 Stem Cell and Regenerative Therapies

Regenerative medicine offers the potential to restore endogenous insulin production through stem cell–derived β-cell

replacement. Advances in stem cell differentiation have enabled the generation of functional insulin-producing cells, demonstrating proof-of-concept for biological restoration of glucose regulation (Pagliuca et al., 2014). Early clinical studies have shown promising results; however, barriers such as immune rejection, need for immunosuppression, high cost, and scalability continue to limit widespread application.

7. Health System Challenges and Strategic Priorities in Thailand

Despite advances in diabetes care, significant health system challenges continue to limit effective implementation in Thailand. These challenges span access to care, workforce capacity, policy alignment, and real-world integration of emerging innovations.

7.1 Access to Care

Access to essential diabetes services remains uneven, particularly between urban and rural areas. While basic treatments such as metformin and insulin are widely available, access to newer therapies including SGLT2 inhibitors, GLP-1 receptor agonists, and advanced technologies such as continuous glucose monitoring (CGM) is often constrained by cost and reimbursement limitations (Atun et al., 2017). In addition, gaps in screening and early diagnosis contribute to delayed treatment initiation and increased risk of complications (International Diabetes Federation, 2024; Mahikul et al., 2019).

7.2 Workforce Capacity

Effective diabetes management requires a multidisciplinary approach involving physicians, nurses, pharmacists, and allied health professionals. However, workforce shortages, particularly in primary care and rural settings, limit the capacity for continuous, patient-centered care. Structured diabetes education and self-management support programs are not consistently integrated into routine practice, reducing opportunities for prevention and long-term disease control (Atun et al., 2017).

7.3 Policy Gaps

Although Thailand has made progress in addressing noncommunicable diseases, gaps remain in aligning national policies with rapidly evolving clinical and technological advances. Coverage of newer pharmacological agents and digital health tools is limited, and integration of precision medicine and early detection strategies into national frameworks is still evolving. These gaps hinder the translation of scientific advances into population-level benefits.

7.4 Implementation Challenges

The implementation of innovative diabetes care models—such as telemedicine, AI-assisted screening, and integrated chronic care pathways—faces practical barriers, including digital infrastructure limitations, variable health literacy, and challenges in data governance. Fragmented care delivery systems further complicate coordination across levels of care, reducing efficiency and continuity (Atun et al., 2017). Addressing these challenges requires strengthening primary care systems, expanding digital health capacity, and improving coordination across healthcare sectors.

7.5 Strategic Priorities

To improve diabetes outcomes in Thailand, strategic priorities should focus on strengthening early detection through population-based screening, expanding equitable access to essential and advanced therapies, and integrating multidisciplinary care within primary healthcare systems. Investment in workforce development, digital infrastructure, and policy frameworks that support innovation adoption will be critical. Aligning these efforts with prevention-focused public health strategies can enhance long-term sustainability and reduce the growing burden of diabetes.

Conclusion

This review shows that diabetes mellitus has evolved from a glucose-centered disorder to a complex, multisystem condition requiring

biologically precise, technology-enabled, and health-system–integrated strategies. Across epidemiology, mechanisms, diagnostics, complications, and emerging therapies, the evidence supports a shift toward predictive, personalized, and prevention-oriented care. Scientific advances—including SGLT2 inhibitors and GLP-1 receptor agonists for cardiorenal protection, immunotherapy for type 1 diabetes, continuous glucose monitoring, AI-assisted screening, and stem-cell–based approaches—demonstrate real clinical progress.

However, translation into population-level impact remains uneven. Complications continue to drive morbidity and mortality, particularly in middle-income settings such as Thailand, where rising young-onset type 2 diabetes, population aging, fragmented chronic-care systems, and unequal access to advanced technologies limit implementation. Aligning innovation with health-system strengthening—through early detection, integrated cardiometabolic risk management, digital infrastructure, workforce development, and equitable access—is essential to improve long-term outcomes in both global and Thai contexts.

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