Journal of Chemical Health Risks

www.jchr.org

JCHR (2026) 16(2), 1030-1044 | ISSN:2251-6727

Type 1 Diabetes Mellitus: Epidemiology, Pathogenesis, Disease Staging and Emerging Therapeutic Strategies

Sayda Fareen[1], Rubeen Nadaf[1*], Vaishanavi Huddar[1], Kiran Kadam[1], Ramesh Paranjape[1], NaseemAnjum Topinkatti[1]

Affiliation [1] Dr. Prabhakar Kore Basic Science Research Center, Jawaharlal Nehru Medical College, Belagavi – 590010. Karnataka, India.

[1*] Dr. Prabhakar Kore Basic Science Research Center, Jawaharlal Nehru Medical College, Belagavi – 590010. Karnataka, India.

Corresponding Author

Rubeen D. Nadaf[1*], Dr. Prabhakar Kore Basic Science Research Center, Jawaharlal Nehru Medical College, Belagavi – 590010. Karnataka, India.

(Received: 16 January 2026 Revised: 25 February 2026 Accepted: 17 March 2026)

KEYWORDS

Type 1 diabetes mellitus; Autoimmunity; Islet autoantibodies; Disease staging; Immunotherapy; Precision medicine

ABSTRACT:

Background and aims:

Type 1 diabetes mellitus (T1DM) is a heterogeneous autoimmune disorder characterized by immune-mediated β-cell destruction and lifelong insulin dependence, with a rising global incidence. This review summarizes current evidence on its epidemiology, immunopathogenesis, disease staging, and emerging therapeutic strategies

Methods:

A narrative review of the literature was undertaken using articles from peer-reviewed journals in prominent scientific databases. The evidence with respect to trends in epidemiology, genetic and environmental risk factors, immunopathogenesis, autoantibody profiles, presymptomatic disease staging, clinical manifestations, and progress in therapeutic approaches was carefully evaluated. Special attention was given to disease heterogeneity, advances in translation and the current practice in India in the setting of socioeconomic and healthcare infrastructure challenges.

Conclusions:

T1DM is a complex, heterogeneous autoimmune disease characterized by a prolonged presymptomatic phase and evolving understanding of genetic and immunological mechanisms. Emerging advances in precision medicine, immunotherapy, and regenerative strategies offer promising avenues for disease modification, although equitable access and healthcare challenges remain, particularly in developing countries.

1. Introduction

Journal of Chemical Health Risks

www.jchr.org

JCHR (2026) 16(2), 1030-1044 | ISSN:2251-6727

The Pancreas plays a central role in maintaining glucose homeostasis through the regulated secretion of insulin, a peptide hormone synthesized by beta cells with the islets of Langerhans (Fig.1). Insulin facilitates the uptake of glucose derived from dietary carbohydrates into insulin sensitive tissues including skeletal muscle and adipose tissue while simultaneously suppressing hepatic glucose production. Disruption of this finely balanced system results in persistent hyperglycemia, the defining biochemical feature of diabetes mellitus. In diabetes, either insulin production is insufficient or the biological response to insulin is impaired leading to widespread metabolic dysregulation affecting carbohydrate, lipid and protein metabolism [1] .

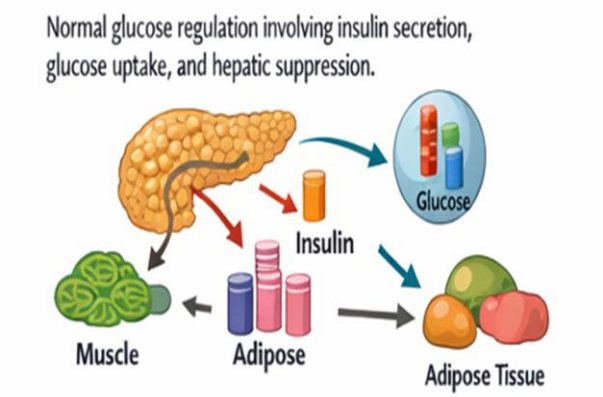

Figure 1. Normal Glucose Homeostasis and Insulin Function

Figure 1: Physiological regulation of blood glucose showing insulin secretion from pancreatic β-cells and insulin-mediated glucose uptake in peripheral tissues, maintaining normal glycemic balance

Diabetes mellitus constraints a major global public health challenge due to its rising prevalence and its association with long-term complications such as diabetic kidney disease, cardiomyopathy, neuropathy, retinopathy, impaired wound healing and diabetic foot ulcers that is all of which substantially contribute to morbidity and its premature mortality [2] .

Among the broad spectrum of diabetes mellitus, type 1 diabetes melinites (T1DM) is clearly defined autoimmune disease that involves destruction of insulin secreting beta cells mediated by immune responses (Fig. 2). This results in a total or near complete deficiency of insulin and the requirement for life long replacement therapy with injected insulin to survive. While T1DM represents a smaller percentage of the total prevalence and incidence of diabetes relative to type 2 diabetes; its clinical impact is considerable because of its young age at diagnosis, lifetime management needs and high risk for acute and chronic complications. Global estimated project that is up to 693 million people will be living with diabetes worldwide by 2045 as a result of rapid demographic shifts, changing environmental conditions, and shifting disease determinants. In this growing tendency of T1DM still grows in incidence thus refuting the previous belief that it is constant and genetically driven [3].

Figure 2. Pathogenesis of Type 1 Diabetes Mellitus

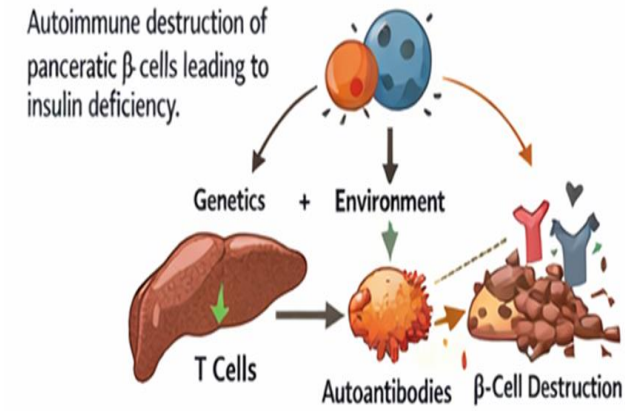

Figure 2: Autoimmune destruction of pancreatic β-cells driven by genetic susceptibility and environmental triggers, resulting in absolute insulin deficiency and chronic hyperglycemia.

The epidemiological data collected by the international Diabetes Federation, it has been established that hundreds of million adults across the globe are have been affected and continue to be influenced by diabetes. Moreover, third party projections have confirmed that this trend is scheduled to increase drastically in coming years. Type 1 diabetes, although relatively less common than type 2, has been recognized for its steady increase in prevalence over time, regardless of the region [4] .

In 2021, it was identified that a total of 8.4 million people across the globe live with T1DM. Approximately 18% of all those influenced by T1DM were found to be younger than 20 years of age. Furthermore, it has been established that close to half million new cases of T1DM

Journal of Chemical Health Risks

www.jchr.org

JCHR (2026) 16(2), 1030-1044 | ISSN:2251-6727

are identified each year, with these projections estimated to increase by between 60 to over 100% by the year 2040. This trends highlight the urgent need to understand the factors driving disease emergence and progression, particularly in populations historically considered at low risk [5] .

As India is emerging region that holds significant importance in the world-wide epidemiology of T1DM. At present, there are around 97,700 children who are diagnosed with the disease, with a higher prevalence evident than previously known, particularly in south and Southeast Asia. Population-based studies from South India have provided critical insights into the disease distribution, diagnostic patterns, and the clinical presentation, revealing that immune-mediated beta-cell destruction often progresses rapidly in the children, leading to earlier insulin dependence and higher risk of ketoacidosis at diagnosis. In contrast as per adults may experience a slower disease course with greater residual beta cell functions at onset, underscoring the age related heterogeneity in disease pathogenesis [6] .

One of the hallmark features of T1DM is that, unlike other forms of Diabetes Melinites, it has an extended prodromal phase, in which disease joins with its autoimmune aspects and established through hyperglycemia and as it is not yet obvious and the symptoms are still lacking. The phase is marked by the production of circulating islet cell antibodies, which are targeted specifically at beta cell antigens, insulin, glutamic acid decarboxylase, islet antigen 2 and zinc transport protein 8. This provides strong evidence that the disease process in T1DM begins, although its expression in terms of hyperglycemia is still in abeyance. This recognition of disease stages has dramatically altered the traditional concept of T1DM as an isolated endocrine failure, changing its status to a chronic disease, providing a distinctive model for disease prevention [7] .

Specifically, the recent studies have underscored the importances of systemic networks, including the lipidome, serum metabolome and gut microbiota, beyond classical genetic and environment paradigms in determine the immune response and beta-cell vulnerability. These emerging findings are consistent with a systems biology perspective on T1DM pathogenesis, where genetic predisposition dynamically interacts with environmental exposures and endogenous metabolic states. As such, T1DM has become a model disease other immune mediated conditions including celiac disease, autoimmune thyroid disease and Addisons disease. Accordingly, this conceptual evolution sets the stage for a deeper examination of the epidemiological patters, risk determinants and mechanistic pathways that underlie the development of type 1 diabetes [8].

Epidemiology of Type 1 Diabetes Mellitus

Type 1 Diabetes Mellitus (T1DM): T1DM has a significant geographic, temporal and demographic variation. On the one hand, the prevalence of T1DM is estimated based on the International Diabetes Federation Report as follows: “Approximately 8.4 million people are known to live with T1DM worldwide. Almost 1.5 million of them are children and adolescents. Every year, approximately 400,000 to 500,000 cases are diagnosed with T1DM worldwide, with projections indicating a 60–100% increase in disease burden by 2040. An increase in Prevalence in the context of total cases of diabetes, the long treatment required for T1DM patients along with early age of onset constitutes significant burden” [9] .

Incidence rates vary widely across populations, with the highest rates reported in Finland, Sardinia, Sweden and other Northern European regions, exceeding 50 per 100,000 children per year. Elevated incidence has also been documented in the middle east, North America and Australia. In contrast, East and Southeast Asia historically reported lower incidence; however, these regions are currently experiencing the fastest relative increase, highlighting the growing influence of environmental and societal determinants. Globally, the average annual rise in T1DM incidence is estimated at 3-4%, a trend that cannot be explained by genetic factors alone [10] .

Journal of Chemical Health Risks
www.jchr.org
JCHR (2026) 16(2), 1030-1044 | ISSN:2251-6727

India is a region of growing epidemiological importance, with recent studies indicating close to 100,000 children living with T1DM. Populations based studies suggest that an increasing incidence, delayed diagnosis in certain contexts and notably high prevalence of diabetic ketoacidosis at presentation among children. While improvements in survival and diagnostic awareness have largely contributed to increasingly prevalence across age groups including adults with slowly progressive autoimmune disease prevalence continues to increases. These combined epidemiological trends emphasize the changing phase of T1DM and the need for specific surveillance, early diagnosis and long-term care strategies [11] .

Risk factor

The increasing worldwide occurrence of type 1 diabetes mellitus demonstrates that non-genetic factors function as the primary disease development in populations which have always shown low genetic risk. T1DM shows age related onset patterns and most common incidence occurs during the early years of life through the teenage years which correspond with vital stage of immune system maturation. Epidemiological patterns observed since the mid-twentieth century show a persistent rise in disease incidence which genetic background changes cannot fully account because genetics populations develop across extensive time periods. The temporal discrepancy between environmental factors and life style changes and disease onset in people with genetic susceptibility establishes these two elements as primary factors driving the development of the condition [12] .

The risk factors that increase an individual's chance for developing T1DM include elements of predisposition and external triggers that initiate or perpetuate the immune reaction against pancreatic beta cells (Fig. 3). Studies that show familiar aggregation clearly prove that the risk for developing T1DM for first-degree relatives is significantly higher than of the general population. However, it has also been observed that most T1DM patients who present for care do not have familial or genetic predisposition for diabetes, which emphasizes the need to look into external and developmental factors that can impact T1DM, as emphasized by different sources. Understanding these risk determinants is essential not only for elucidating of the disease mechanisms but also for enabling early prediction, targeted surveillance, and prevention strategies [13].

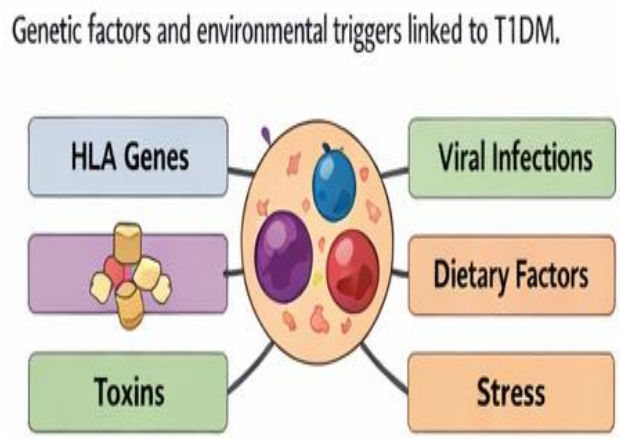

Figure 3. Genetic and Environmental Risk Factors for T1DM

Figure 3: Major genetic predispositions and environmental exposures, including HLA variants, infections, dietary factors, and toxins, contributing to immune dysregulation in T1DM development

Pre-symptomatic Disease and Staging

Type 1 Diabetes is considered a progressive autoimmune disease with a lengthy presymptomatic period preceding the clinical onset of hyperglycemia by months and years. During this latent period, immune-mediated beta-cell destruction has already occurred while glucose homeostasis is still maintained and no overt symptoms. This new paradigm to a chronic immunological disease that has defined stages, offering a window for early detection and intervention [14] .

The modern staging for diabetes mellitus describes disease pathogenesis as being comprised of three distinct phases (Fig. 4). The first phase is marked by the co-existence of two or more islet cell antibodies in circulation along with normoglycemia, which reflects active autoimmune conditions in the absence of any clinical symptoms. Progression to the next phase is indicated by the presence of clinical symptoms being absent and the co-existence of dysglycemia in the form of abnormal fasting glucose levels, abnormal oral glucose tolerance tests and abnormal levels of glycated

Journal of Chemical Health Risks
www.jchr.org
JCHR (2026) 16(2), 1030-1044 | ISSN:2251-6727

haemoglobin. The next phase that characterizes DM is the presence of substantial endogenous that is inadequate to perform its homeostatic function [15] .

Figure 4. Stages of Type 1 Diabetes Progression

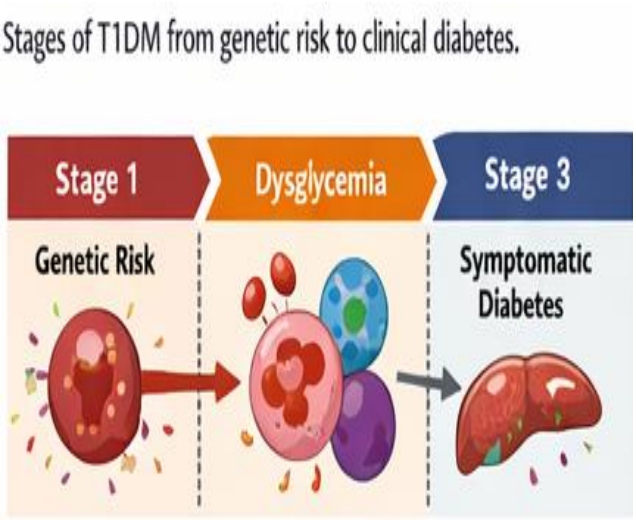

Figure 4: Sequential stages of T1DM from genetic risk and asymptomatic autoimmunity to dysglycemia and clinically overt diabetes.

Longitudinal cohort studies have established that all individuals who present with multiple islet cell antibodies will ultimately manifest clinical disease, through the rate of disease progression is varied. Older age at time of time of antibody seroconversion, combinations of increased antibody titers and lower rates of residual insulin secretion are associated with rapid disease progression. Current efforts in predictive modelling for T1DM risk estimation have expanded beyond traditional classification by incorporating metabolic markers such as fasting glucose and HBA1c, as well as C-peptide and age. Thus, reaching beyond the classification epoch to a precision medicine approach for pre-symptomatic T1DM to allow for tailored screening options for disease-modifying therapies [16] .

The identification of the preclinical phase has thus established T1DM as an exemplary model of autoimmune disease that exhibit early immune system abnormalities. The observation made from this preclinical phase model have helped guide research into other autoimmune disease that show detectable immunologic abnormalities are also seen in celiac disease and autoimmune thyroid disease. This of course, naturally brings the tissue of genetic influence into the equation [17].

Genetic Susceptibility

Genetic predisposition forms an integral part of the foundation risk for Type 1 Diabetes and the highest risks are associated with regions of chromosomes 6 known as the human leukocyte antigen. These include HLA class II region haplotypes: HLA-DRE-DQ2 and HLA-DR4-DQ8. People harboring both of these haplotypic combinations of HLA have the highest risk of Type 1 diabetes due to additive effects on the highest risk of type 1 diabetes due to additive effects on the immunologic systems. On the contrary, certain HLA components have protective effects on Type 1 diabetes risk and this dichotomy underlines the positive and negative immunologic effects of this region of chromosomes 6 [18].

Beyond the HLA locus, many non-HLA genes are known to have modest but important effects. Non-HLA genes, such as INS, PTPN22, CTLA4, IL2RA, IIFI, etc., are known to affect immune system central and peripheral tolerance, cytokines and antiviral activities. Thus, the balance between immune activation and regulation is determined, thereby affecting beta-cell autoimmunity. While these findings are interesting, genetic factors cannot explain the increased incidence of T1DM, as evidence by an increased incidence of the disease in individuals with low genetic risk profiles [19].

Importantly, genetic influences seem to have stage-specific effects throughout disease development. While some alleles are more directly involved in the initiation of autoimmunity, others influence the rate of beta-cell destruction and the progression toward overt diabetes. This nuanced role of genetics again emphasizes the notion that inherited risk confers permissiveness to the immune system but that environmental exposures represent critical inducers required for disease manifestation [20].

Environmental Risk Factors

The contribution of environmental influences to T1DM risk is further reinforced by observations that disease incidence correlates more closely to its environmental

Journal of Chemical Health Risks

www.jchr.org

JCHR (2026) 16(2), 1030-1044 | ISSN:2251-6727

context than its ethnic origins. Thus, extensive research efforts have centered on the potential environmental triggers of T1DM that may initiate or exacerbate autoimmune destruction of the beta cells, even though none has been reliably implicated as casual in individual case, a converging body of evidence supports that T1DM is the result of a combination of influences [21].

Infectious Agents

There has also been evidence of viral infections causing type 1 diabetes and among all enterovirus, among those, Coxsackie B viruses, are at the forefront. Various types of molecular mechanisms have been put forward to explain the association that exists. They include molecular mimicry, bystander immunity and direct infection. The presence of enteroviral RNA has also been found in pancreatic tissues and blood of patients suffering from T1DM, thus providing evidence for a biological link but causality is risky [22].

It seems the timing, nature and immunological environment surrounding viral infections may be a key variable in the risk for subsequent diseases. Early-life infections may shape the immune systems maturation process and tolerance mechanism; repeated and persistent infections may stimulate increased inflammatory reactivities contributing to autoimmunity. In addition, to the population epidemiology studies such as decreased risk of T1DM from widespread prevalence of a rotavirus vaccine further substantiate the proposal that virus can contribute to the initiation of disease. This further supports the need to incorporate virus exposure into broader models of environmental risk [23].

Nutritional and Environmental Exposures

Environmental exposures are also very important for modulating the risk for type 1 diabetes, especially for those with a genetic predisposition to the development of the condition. For instance, infant nutrition has also been extensively investigated for its role in modulating risk for type 1 diabetes because of its effect on the developing immune system as well as metabolic development. Exposures to breastfeeding for extended period of time, infant exposure to cow's milk and its protein, exposure to gluten and vitamin D levels have been investigated with mixed outcomes. Despite a modest protective effect from prolonged breastfeeding and vitamin D levels, no dietary exposure has been clearly linked to the pathogenesis of type 1 diabetes [24].

Dietary patterns later in childhood and adolescence may influence disease progression by promoting systemic inflammation, altering insulin sensitivity, and shaping gut microbiota composition. Diets high in saturated fats and refined carbohydrates have been associated with pro-inflammatory metabolic states that could accelerate beta-cell dysfunction in individuals with ongoing autoimmunity, although confounding lifestyle factors complicate interpretation [25].

Exposure to environmental pollutants like pesticides, nitrates, persistent organic chemicals and endocrine-disrupting chemicals has also been linked to autoimmune disease risk. For instance, exposure to these chemical agents may lead to oxidative stress, dysregulation of the immune system and disruption of hormones thus rendering beta cells more susceptible to destruction. Although there is sufficient evidence from study models, evidence from human populations is inconsistent because it is difficult to measure exposure to these environmental agents and also because of long disease latencies. Together, findings from current research indicate the nutritional factors and chemicals play key roles to play in T1DM risk, but they should be viewed from an environmental perspective [26].

Psychosocial and Socioeconomic Factors

The psychosocial effects of stress and the socioeconomic environment are also known to affect the overall state of the human immune system. Stress is believed to accelerate the progression of autoimmune diseases by altering the levels of cortisol in the body and the overall inflammatory responses, though the relationship between stress-induced immune compromise and the development of T1DM is not entirely clear. The connection between socioeconomic status and the overall outcomes in T1DM, however, is starker, as delayed diagnosis, ketoacidosis, and poor glycemic control have been observed in these patients [27] .

Limited access to healthcare, reduced health literacy, and financial barriers to optimal therapy contribute to these disparities, particularly in low- and middle-income settings. These factors do not initiate autoimmunity per se but significantly modulate disease expression,

Journal of Chemical Health Risks

www.jchr.org

JCHR (2026) 16(2), 1030-1044 | ISSN:2251-6727

progression, and complications, reinforcing the importance of social determinants in shaping the overall burden of T1DM [28].

Prenatal and Perinatal Influences

Events during pregnancy and early life have long-lasting implications on the development of the immune system and regulation of metabolism. Therefore, these periods can be considered critical periods in disease development, also known as disease susceptibility. Factors like maternal age, pre-pregnancy obesity, gestational diabetes, smoking, mode of delivery, birth weight, and gestational age have shown links to slight modifications in T1DM susceptibility. These conditions may affect fetal development, immune system, and microorganisms, which may later be linked to altered autoimmune susceptibility [29].

Although individual effect sizes are generally small, the cumulative impact of multiple prenatal and perinatal exposures may be substantial at the population level. These observations highlight the importance of maternal health and early-life interventions as components of comprehensive prevention strategies [30].

Omics Approaches and the Exposome

High-throughput "omics" research has completely altered the field's perspective in understanding type 1 diabetes with the help of the integrative analysis of genetic, epigenetic, transcriptomic, metabolomic, lipidomic, and microbiome-related changes preceding the onset of T1DM. Longitudinal cohorts have now identified changes in lipid metabolism, amino acid signatures, and patterns of gut microbiome months to years in advance of autoantibody-driven clinical onset in islet autoantibodies; these changes may be useful in developing early-onset biomarkers of T1DM immunopathology [31]. This perspective has converged with the 'exposome' concept—defining disease risk in T1DM and other conditions with the help of the combined effects of a person's genetic predisposition and their exposure to environmental factors at various stages in their life. Though challenges in T1DM exposome exist due to its complex nature, it possesses immense value in developing novel understanding in T1DM with the help of systems-based approaches to developing novel approaches in T1DM pathology [32].

Clinical Features

Clinical presentation of Type 1 diabetes mellitus occurs when the autoimmune destruction of the pancreatic beta cells surpasses a critical threshold at which time the body is no longer capable of maintaining its own insulin homeostasis. The clinical presentation correlates with the surviving beta-cell function, rate of autoimmune destruction, and age at the time of presentation. As diabetes has classically been perceived as affecting children only, it is now clear that a large percentage of Type 1 diabetics are being diagnosed in later ages as an increasingly insidious process [33].

Classical symptoms associated with the diagnosis also include polyuria, polydipsia, polyphagia, weight loss, fatigue, and blurred vision due to hyperglycemia and osmotic diuresis (Fig. 5). Children also may have acute presentation with a considerable number manifesting diabetic ketoacidosis at presentation, mostly due to slow recognition of the disease. Unlike adults, patients may manifest with subtle or asymptomatic hyperglycemia due to slow beta-cell cell death and preservation of insulin secretion during the early course of the disease [34].

Figure 5. Immune-Mediated β-Cell Destruction

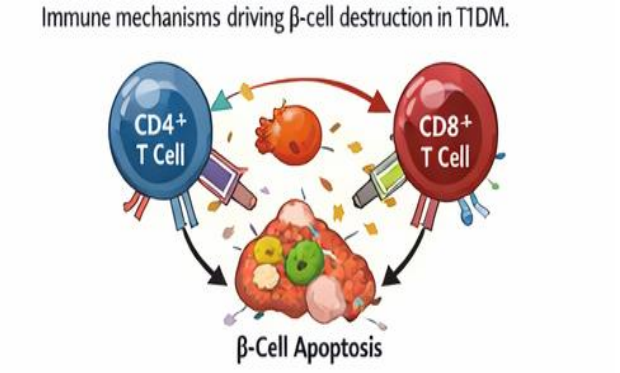

Figure 5: Role of $CD4^+$ and $CD8^+$ T cells, cytokines, and inflammatory pathways in progressive pancreatic β-cell apoptosis during T1DM

Diabetic ketoacidosis is considered to be one of the most severe and life-threatening acute complications of T1DM; it is caused by insulin severity, hyperglycemia, ketosis, and metabolic acidosis. Koehler et al.\ attributed ketoacidosis to be the initial cause in younger patients; it includes increased morbidity and mortality, especially in resource-constrained societies. Repeated ketoacidotic

Journal of Chemical Health Risks
www.jchr.org
JCHR (2026) 16(2), 1030-1044 | ISSN:2251-6727

episodes have often been related to glycemic patterns, psychosocial aspects, and complications related to insulin availability. There exists a significant relationship between disease processes and health systems [35].

After the diagnosis and initiation of insulin therapy, human subjects demonstrate a temporary "honeymoon phase." During this period, the requirements of exogenous insulin are low. This is because there is a partial healing of beta cell functions, and glucotoxicity is also low. This period is temporary and varies considerably as a result of age of onset, intensity of insulin, and degree of immunologic activity. This temporary period is a critical requirement for preserving the residual mass of the beta cells and has been associated with improved metabolic stability and a reduction in the chances of complications [36].

Ultimately, the effects of chronic hyperglycemia and glycaemia variability culminate in microvascular complications, including retinopathy, neuropathy, as well as muscular complications (Fig. 6). The complications have been significantly reduced with the advancement of insulin therapy and blood glucose monitoring, especially in high-income populations; inequalities exist globally. Clinical expression of T1DM is therefore best understood as a dynamic continuum influenced by immunological activity, metabolic control, age, and socioeconomic context. Common clinical manifestations and diagnostic indicators of T1DM, including polyuria, polydipsia, weight loss, hyperglycemia, and islet autoantibodies [37] .

Figure 6. Clinical Features and Diagnosis of T1DM

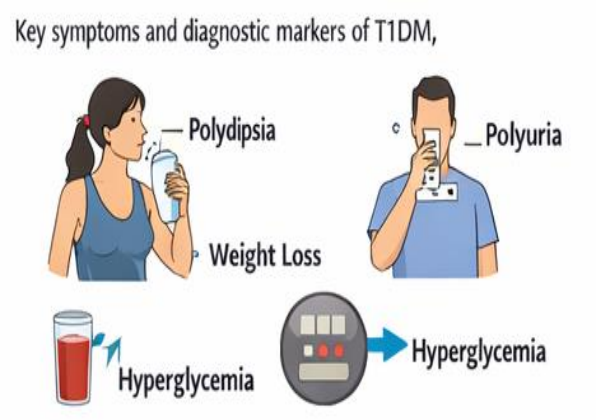

Figure 6: Common clinical manifestations and diagnostic indicators of T1DM, including polyuria, polydipsia, weight loss, hyperglycemia, and islet autoantibodies

Pathophysiology, Classification and Heterogeneity of Type 1 Diabetes

While the basic pathophysiological process of type 1 diabetes lies in the abnormal destruction of insulin-producing pancreas cells called as beta cells, it is the result of the complex interaction of the innate and acquired immune response, which is both genetic and environmental in origin. $CD4^+$ and $CD8^+$ T cells of the immune system have the principal role in the destruction of the insulin-producing beta cells, while B cells of the immune system contribute to tissue damage through the production of antibodies, which activate the process of antigen presentation by macrophages and dendritic cells (Fig 7). At a molecular level, increased stress in the beta cells brought about by a viral infection, inflammatory cytokines, or metabolic disturbances might stimulate antigen presentation and induce an immune response [38]. Specifically, pro-inflammatory cytokines like IL-1β, interferon γ, and tumor necrosis factor-alpha trigger endoplasmic reticulum stress, oxidative stress, and apoptosis in beta cells, creating a vicious cycle by continuously exposing more autoantigen determinants to the hyperactive autoimmune response [39].

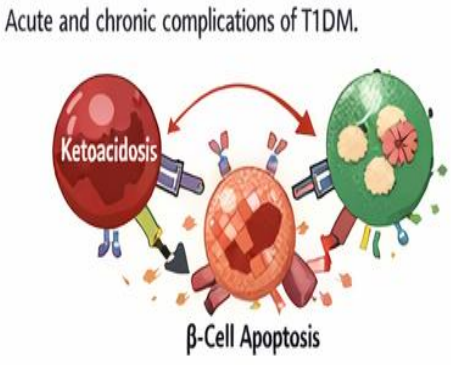

Figure 7. Acute and Chronic Complications of Type 1 Diabetes

Figure 7: Overview of acute complications such as diabetic ketoacidosis and long-term microvascular and

Journal of Chemical Health Risks
www.jchr.org
JCHR (2026) 16(2), 1030-1044 | ISSN:2251-6727

macrovascular complications associated with sustained hyperglycemia.

For a long time, type 1 diabetes was treated like one uniform illness. Yet recent findings show clear differences across its immune, metabolic, and body-related aspects. Differences appear in when it starts, how fast pancreas cells are lost, which autoantibodies show up, and how patients react to treatment. In kids, the condition usually moves fast with broad immune activation, many autoantibodies, then quick loss of insulin production. In grown-ups, it may unfold more slowly, often leaving some natural insulin function present at first check-in [40].

These observations have led to an increased focus on the refinement of disease classification, which goes beyond the classification of Type 1 and Type 2 diabetes. Latent autoimmune diabetes in adults refers to an intermediate phenotype associated with autoimmune markers and insulin dependence. The condition often presents as Type 2 diabetes. Furthermore, there are conditions in humans which express both characteristics of insulin resistance and autoimmunity. Hence, the presence of overlapping syndromes highlights the fact that immunological and metabolic markers are required to classify the condition for appropriate management and treatment options [41].

Emerging data also indicate that different endotypes of type 1 diabetes may exist, differing from one another on the basis of immune pathways, genetic backgrounds, and beta-cell susceptibility. The response of these endotypes to immunomodulatory therapies may vary, and the rate of disease progression may also differ among them. Research into these areas is currently the focus of interest, as the possibility of using precision medicine practices to the benefit of individuals exists [42].

Such changes in the concept of T1DM being a heterogeneous autoimmune endocrine organ-specific disease are very important for the development of therapies for type 1 diabetes. As discussed, type 1 diabetes was considered a singular disease, but the multifaceted aspects of the disease are now brought together under a new concept where type 1 diabetes encompasses a range of related disorders that are distinguished by their pathobiology but are linked by the presence of insulin deficiency. This gives rise to the hope for new therapeutic options that are not merely focused on insulin replacement [43].

Treatment

The management strategy of type 1 diabetes mellitus essentially includes insulin replacement therapy that demands education, dietary planning, blood glucose monitoring, and even psychosocial intervention. The prime intention of any management strategy is to mimic physiological glucose levels by minimizing the risk of hypoglycemia and reducing the risk of all microvascular and macrovascular complications. Better physiological outcomes have been made possible through progress made in insulin therapy and glucose monitoring; however, the management of type 1 diabetes is complex and individualized (Fig. 8). Indications for Insulin Therapy: Insulin therapy needs to replicate the biological basal and prandial insulin secretions by intermittent administration of exogenous insulin or continuous subcutaneous insulin infusion [44]. Basal-bolus regimens using long-acting insulin analogues with meals containing rapid-acting insulin are the most commonly practiced method within clinical practice. Continuous glucose sensors are revolutionizing the treatment of diabetes by giving immediate feedback, allowing timely diagnosis of hypoglycemic attacks, and adjusting insulin doses. Hybrid closed-loop systems using continuous subcutaneous infusion pumps plus glucose algorithms are a landmark advance in diabetes treatment technology, although access is still restricted in various countries [45].

Figure 8. Therapeutic Strategies for Type 1 Diabetes Mellitus

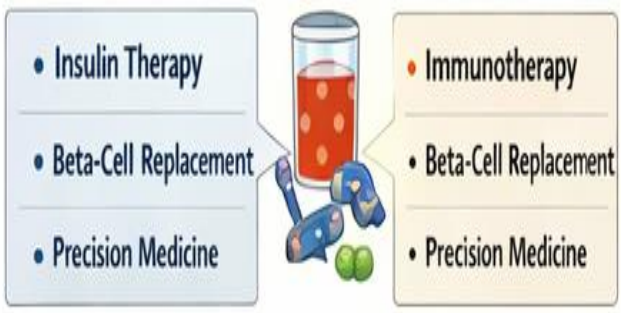

Figure 8: Current and emerging therapeutic approaches for T1DM, including insulin therapy,

Journal of Chemical Health Risks

www.jchr.org

JCHR (2026) 16(2), 1030-1044 | ISSN:2251-6727

immunomodulation, β-cell replacement, and precision medicine strategies

Adjunctive therapies that address metabolic stability through different pathways besides glycemia have been used to minimize the degree of insulin dependency. These include pramlintide, an amylin analogue that reduces the severity of post-meal glucose increases through the slowing of gastric emptying and the reduction of glucagon release; however, its administration is limited by gastrointestinal side effects. Immunomodulatory regimens that seek to retain the function of the residual beta-cell mass have been shown to help stabilize the progression of the disease process if administered in the initial stages of the disease, emphasizing the fact that type 1 diabetes is indeed amenable to intervention [46].

Finally, effective management goes beyond pharmacotherapy to include extensive diabetes education, balanced dietary management, and physical activity. It should be noted that psychosocial management is particularly critical since it addresses the overwhelming demands imposed by insulin therapy and glucose monitoring. The use of a multidisciplinary approach has consistently been shown to generate better outcomes compared to a fragmented approach [47].

Standard of Care in India

The standard of care for type 1 diabetes care in India reflects a combination of international guidelines and local realities in terms of resource constraints and diversity in terms of socioeconomic status and regional variability. Therefore, insulin therapy is the mainstay of care; namely, multiple daily injections with human insulin or insulin analogues is the most commonly used insulin therapy regimen. Despite the pharmacokinetic advantages of insulin analogues and their impact on hypoglycaemia risk, cost constraint constitutes an impediment to the routine use of insulin analogues in public health practice [48].

Blood glucose measurement mainly happens through self-monitoring devices like glucometers. This is because continuous glucose monitoring systems are not always available to everyone due to financial constraints and infrastructure. However, their availability can be witnessed in urban centers and hospitals, especially of tertiary nature, as awareness about these devices rises with an improvement in insurance schemes [49]. Even diabetes education programs have a very significant place to fill by reducing problems like diabetic ketoacidosis among patients.

Lately, national efforts to manage non-communicable illnesses have begun recognizing how kids and teens with type 1 diabetes face unique struggles. While better testing, steady insulin access, and weaving diabetes services into basic care have made real differences, hurdles remain. In remote regions, recognition often lags, leading to late diagnoses - one of many ongoing issues. Families find it hard when there are no skilled workers nearby to handle care needs. Cost matters too; paying out of pocket weighs heavily on those dealing with the condition across several generations [50].

Despite these challenges, India has emerged as a leader in innovative care models for type 1 diabetes, including community-based follow-up, mobile health interventions, and telemedicine platforms. These approaches have the potential to bridge gaps in access and improve long-term outcomes, particularly when combined with policy-level support for affordable insulin and diagnostic technologies [51].

Gene Therapy for Type 1 Diabetes

Gene therapy stands as a bold path toward ending type 1 diabetes, aiming directly at the root causes instead of blood sugar management. Researchers now explore putting genes for insulin - or those that control its regulation - into cells other than beta cells, while also trying to calm immune reactions, boost lifespan of existing beta cells, and spark new beta cell growth. Progress in vectors, whether viral or non-viral, allows more precise delivery and fewer side effects, making real-world application more reachable [52].

A fresh path opens by turning liver or gut cells into insulin makers, triggered by blood sugar levels, this skips the immune system's attack on pancreas beta cells. Instead of drugs, some researchers tweak genes to calm aggressive immune responses or guide helpful immune actions. Tools like CRISPR-Cas can now fix faulty DNA pieces tied to immune system imbalances, yet moral questions and health risks still weigh heavily [53].

Journal of Chemical Health Risks

www.jchr.org

JCHR (2026) 16(2), 1030-1044 | ISSN:2251-6727

Even though early tests look promising, moving gene therapy from labs to patients isn't straightforward. One issue is keeping genes active for more than short periods. Another problem shows up when treatments act on wrong cells by mistake. Reactions from the body's defence system can also block progress. Disease causes differ between people, adding complexity. In type 1 diabetes, immune system damage makes things harder. New beta cells might survive longer, yet still be targeted if immunity isn't balanced at the same time [54].

As research progresses, gene therapy is increasingly viewed not as a standalone cure but as a component of combination strategies that integrate immune modulation, beta-cell replacement or regeneration, and metabolic control. Continued advances in delivery technologies and a deeper understanding of disease endotypes will be essential to realize the therapeutic potential of gene-based interventions [55].

Prevention

The discovery that a pre-symptomatic phase is a normal part of type 1 diabetes, however, has radically changed type 1 diabetes research at a preventive level, from theoretical preventive measures to targeted measures that correspond to a particular phase. The primary goal is to decrease the incidence of islet cell immunity in genetic risk groups, while the secondary goal is to prolong, prevent, or delay the progression to disease from autoimmunity. Tertiary preventive measures emphasize preventing further metabolic deterioration [56].

Some drugs aimed at the root causes of autoimmunity can slow diseases, start in people likely to develop type 1 diabetes, showing it might be changed or stopped early. Trying to protect against certain viruses, adjusting gut bacteria, or fine-tuning diet patterns in young lives remains a topic of research - but outcomes differ widely. Because so many factors contribute to illness, tackling more than one piece at once could lead to real protection [57].

The challenges to a population-level approach to prevention centre around costs, ease, as well as ethical considerations, especially in low- and middle-income countries. The identification of at-risk individuals through genetic or immunological screening must be achieved for targeted interventions to be effective, but well-established infrastructure is required to keep this goal afloat. Fortunately, international collaboration has continued to improve predictive tools even as prospective large cohorts have been assembled [58].

Conclusion

Type 1 diabetes mellitus is a highly complex mediated, heterogeneous autoimmune condition, which is characterized by the extensive destruction of the pancreatic beta cells and life-long dependence on exogenous insulin. Sudden breakthroughs in genetics, immunology, and omic approaches have dramatically altered biological understanding of disease pathogenesis, which is marked by an extensive pre-symptomatic phase coupled with considerable modification of risk factors. This has given rise to the emergence of novel therapeutic and preventive strategies for T1 diabetes beyond simply controlling hyperglycaemia.

Regardless, there is still room for improvement, especially in providing the best level of care within variable socioeconomic statuses. For instance, in developing countries especially in India, there is a need to enhance the health system, ensure early diagnosis, and the affordability of insulin and monitoring devices will be a priority. Moving forward, the integration of precision medicine, immunotherapy, and gene therapy has the potential to redefine the course of T1D, hence reducing the burden of the disease.

Acknowledgement: The authors would like to thank Dr. Ramesh Paranjape, Director of Dr. Prabhakar Kore Basic Science Research Center, for his valuable comments on an earlier draft of this manuscript. We are also grateful to the Dr. Prabhakar Kore Basic Science Research Center for providing necessary facilities for literature searches.

Author contributions: RN conceived the review topic and outlined the structure; KK and VH conducted the literature search; RN & SF analysed the data; SF wrote the first draft; RN and RS revised the manuscript. All authors critically reviewed the manuscript and approved the final version.

Conflict of interest: The authors declare no conflict of interest.

Journal of Chemical Health Risks

www.jchr.org

JCHR (2026) 16(2), 1030-1044 | ISSN:2251-6727

Funding Statement: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of generative AI use

The authors declare that they have used generative artificial intelligence, specifically ChatGPT in the creation of images and their corresponding captions

Figure Ligands:

Figure 1. Normal Glucose Homeostasis and Insulin Function

Figure 2. Pathogenesis of Type 1 Diabetes Mellitus

Figure 3. Genetic and Environmental Risk Factors for T1DM

Figure 4. Stages of Type 1 Diabetes Progression

Figure 5. Immune-Mediated β-Cell Destruction

Figure 6. Clinical Features and Diagnosis of T1DM

Figure 7. Acute and Chronic Complications of Type 1 Diabetes

Figure 8. Therapeutic Strategies for Type 1 Diabetes Mellitus

Refrences

[1] M. S. Rahman *et al.*, "Role of Insulin in Health and Disease: An Update," *Int. J. Mol. Sci.*, vol. 22, no. 12, p. 6403, Jan. 2021, doi: 10.3390/ijms22126403.

[2] F. W. A. Waibel, I. Uçkay, L. Soldevila-Boixader, C. Sydler, and K. Gariani, "Current knowledge of morbidities and direct costs related to diabetic foot disorders: a literature review," *Front. Endocrinol.*, vol. 14, p. 1323315, Jan. 2024, doi: 10.3389/fendo.2023.1323315.

[3] M. S. Popoviciu, N. Kaka, Y. Sethi, N. Patel, H. Chopra, and S. Cavalu, "Type 1 Diabetes Mellitus and Autoimmune Diseases: A Critical Review of the Association and the Application of Personalized Medicine," *J. Pers. Med.*, vol. 13, no. 3, p. 422, Feb. 2023, doi: 10.3390/jpm13030422.

[4] Md. J. Hossain, Md. Al-Mamun, and Md. R. Islam, "Diabetes mellitus, the fastest growing global public health concern: Early detection should be focused," *Health Sci. Rep.*, vol. 7, no. 3, p. e2004, Mar. 2024, doi: 10.1002/hsr2.2004.

[5] G. D. Ogle *et al.*, "Global type 1 diabetes prevalence, incidence, and mortality estimates 2025: Results from the International diabetes Federation Atlas, 11th Edition, and the T1D Index Version 3.0," *Diabetes Res. Clin. Pract.*, vol. 225, p. 112277, Jul. 2025, doi: 10.1016/j.diabres.2025.112277.

[6] K. M. P. Kumar, "Incidence trends for childhood type 1 diabetes in India," *Indian J. Endocrinol. Metab.*, vol. 19, no. Suppl 1, pp. S34–S35, Apr. 2015, doi: 10.4103/2230-8210.155378.

[7] T. A. Addissouky, M. M. A. Ali, I. E. T. El Sayed, and Y. Wang, "Type 1 diabetes mellitus: retrospect and prospect," *Bull. Natl. Res. Cent.*, vol. 48, no. 1, p. 42, Apr. 2024, doi: 10.1186/s42269-024-01197-z.

[8] E. M. Brown, J. Clardy, and R. J. Xavier, "Gut microbiome lipid metabolism and its impact on host physiology," *Cell Host Microbe*, vol. 31, no. 2, pp. 173–186, Feb. 2023, doi: 10.1016/j.chom.2023.01.009.

[9] "Epidemiology of type 1 diabetes mellitus in children and adolescents: A 50-year, single-center experience - Kandemir - 2024 - Journal of Diabetes - Wiley Online Library." Accessed: Feb. 26, 2026. [Online]. Available: https://onlinelibrary.wiley.com/doi/10.1111/1753-0407.13562?utm_medium=article&utm_source=researchgate.net

[10] A. Gomber *et al.*, "Variation in the incidence of type 1 diabetes mellitus in children and adolescents by world region and country income group: A scoping review," *PLOS Glob. Public Health*, vol. 2, no. 11, p. e0001099, Nov. 2022, doi: 10.1371/journal.pgph.0001099.

[11] T. Rittiphairoj, M. Owais, Z. J. Ward, C. L. Reddy, J. M. Yeh, and R. Atun, "Incidence and prevalence of type 1 diabetes and diabetic ketoacidosis in children and adolescents (0–19 years) in Thailand (2015–2020): A nationwide population-based study," *Lancet Reg. Health - West. Pac.*, vol. 21, p. 100392, Apr. 2022, doi: 10.1016/j.lanwpc.2022.100392.

[12] D. Traversi *et al.*, "Risk factors for type 1 diabetes, including environmental, behavioural and gut microbial factors: a case–control study," *Sci. Rep.*, vol. 10, no. 1, p. 17566, Oct. 2020, doi: 10.1038/s41598-020-74678-6.

[13] K. Zorena, M. Michalska, M. Kurpas, M. Jaskulak, A. Murawska, and S. Rostami, "Environmental Factors and the Risk of Developing Type 1 Diabetes—Old Disease and New Data," *Biology*, vol. 11, no. 4, p. 608, Apr. 2022, doi: 10.3390/biology11040608.

Journal of Chemical Health Risks

www.jchr.org

JCHR (2026) 16(2), 1030-1044 | ISSN:2251-6727

[14] R. A. Insel *et al.*, "Staging Presymptomatic Type 1 Diabetes: A Scientific Statement of JDRF, the Endocrine Society, and the American Diabetes Association," *Diabetes Care*, vol. 38, no. 10, pp. 1964–1974, Oct. 2015, doi: 10.2337/dc15-1419.

[15] E. D. Abel *et al.*, "Diabetes mellitus—Progress and opportunities in the evolving epidemic," *Cell*, vol. 187, no. 15, pp. 3789–3820, Jul. 2024, doi: 10.1016/j.cell.2024.06.029.

[16] P. J. Bingley, D. C. Boulware, J. P. Krischer, and the Type 1 Diabetes TrialNet Study Group, "The implications of autoantibodies to a single islet antigen in relatives with normal glucose tolerance: development of other autoantibodies and progression to type 1 diabetes," *Diabetologia*, vol. 59, no. 3, pp. 542–549, Mar. 2016, doi: 10.1007/s00125-015-3830-2.

[17] T. A. Marakhovskaya *et al.*, "Preclinical Diagnosis of Type 1 Diabetes: Reality or Utopia," *Biomedicines*, vol. 13, no. 10, p. 2444, Oct. 2025, doi: 10.3390/biomedicines13102444.

[18] B. A. Lie *et al.*, "The predisposition to type 1 diabetes linked to the human leukocyte antigen complex includes at least one non-class II gene.," *Am. J. Hum. Genet.*, vol. 64, no. 3, pp. 793–800, Mar. 1999, doi: 10.1086/302283.

[19] C. Sharma *et al.*, "Association of variants in PTPN22, CTLA-4, IL2-RA, and INS genes with type 1 diabetes in Emiratis," *Ann. Hum. Genet.*, vol. 85, no. 2, pp. 48–57, Mar. 2021, doi: 10.1111/ahg.12406.

[20] C. C. Robertson *et al.*, "Untangling the genetics of beta cell dysfunction and death in type 1 diabetes," *Mol. Metab.*, vol. 86, p. 101973, Jun. 2024, doi: 10.1016/j.molmet.2024.101973.

[21] K. Zorena, M. Michalska, M. Kurpas, M. Jaskulak, A. Murawska, and S. Rostami, "Environmental Factors and the Risk of Developing Type 1 Diabetes—Old Disease and New Data," *Biology*, vol. 11, no. 4, p. 608, Apr. 2022, doi: 10.3390/biology11040608.

[22] I. Kotsiri, M. Xanthi, C.-M. Domazinaki, and E. Magiorkinis, "The Role of Viral Infections in the Immunopathogenesis of Type 1 Diabetes Mellitus: A Narrative Review," *Biology*, vol. 14, no. 8, p. 981, Aug. 2025, doi: 10.3390/biology14080981.

[23] B. Sundaresan, F. Shirafkan, K. Ripperger, and K. Rattay, "The Role of Viral Infections in the Onset of Autoimmune Diseases," *Viruses*, vol. 15, no. 3, p. 782, Mar. 2023, doi: 10.3390/v15030782.

[24] K. Zorena, M. Michalska, M. Kurpas, M. Jaskulak, A. Murawska, and S. Rostami, "Environmental Factors and the Risk of Developing Type 1 Diabetes—Old Disease and New Data," *Biology*, vol. 11, no. 4, p. 608, Apr. 2022, doi: 10.3390/biology11040608.

[25] A. Sălcudean *et al.*, "Dietary Habits and Their Influence on the Microbiome and Mental Health in Adolescents," *Nutrients*, vol. 17, no. 9, p. 1496, Apr. 2025, doi: 10.3390/nu17091496.

[26] C. Shekhar *et al.*, "A systematic review of pesticide exposure, associated risks, and long-term human health impacts," *Toxicol. Rep.*, vol. 13, p. 101840, Dec. 2024, doi: 10.1016/j.toxrep.2024.101840.

[27] J. Y. Choe, M. Nair, R. Basha, B.-J. Kim, and H. P. Jones, "Defining Early Life Stress as a Precursor for Autoimmune Disease," *Crit. Rev. Immunol.*, vol. 39, no. 5, pp. 329–342, 2019, doi: 10.1615/CritRevImmunol.2020033244.

[28] J.-H. Kang, "Influences of decision preferences and health literacy on temporomandibular disorder treatment outcome," *BMC Oral Health*, vol. 22, no. 1, p. 385, Sep. 2022, doi: 10.1186/s12903-022-02420-x.

[29] J. Pradhan, S. Mallick, N. Mishra, A. Tiwari, and V. D. Negi, "Pregnancy, infection, and epigenetic regulation: A complex scenario," *Biochim. Biophys. Acta BBA - Mol. Basis Dis.*, vol. 1869, no. 7, p. 166768, Oct. 2023, doi: 10.1016/j.bbadis.2023.166768.

[30] L. Almeida-Toledano *et al.*, "Effect of prenatal phthalate exposure on fetal development and maternal/neonatal health consequences: A systematic review," *Sci. Total Environ.*, vol. 950, p. 175080, Nov. 2024, doi: 10.1016/j.scitotenv.2024.175080.

[31] B. B. Misra, C. Langefeld, M. Olivier, and L. A. Cox, "Integrated omics: tools, advances and future approaches," *J. Mol. Endocrinol.*, vol. 62, no. 1, pp. R21–R45, Jan. 2019, doi: 10.1530/JME-18-0055.

[32] E. D. Abel *et al.*, "Diabetes mellitus—Progress and opportunities in the evolving epidemic," *Cell*, vol. 187, no. 15, pp. 3789–3820, Jul. 2024, doi: 10.1016/j.cell.2024.06.029.

[33] S. Roy, P. Pokharel, and J. D. Piganelli, "Decoding the immune dance: Unraveling the interplay between beta cells and type 1 diabetes," *Mol. Metab.*, vol. 88, p. 101998, Jul. 2024, doi: 10.1016/j.molmet.2024.101998.

[34] J. Joseph, "Beyond the Triad: Uncommon Initial Presentations in Newly Diagnosed Type 2 Diabetes Mellitus," *Cureus*, vol. 17, no. 8, p. e89525, doi: 10.7759/cureus.89525.

[35] C. Elendu *et al.*, "Comprehensive review of diabetic ketoacidosis: an update," *Ann. Med. Surg.*, vol. 85, no. 6, pp. 2802–2807, May 2023, doi: 10.1097/MS9.0000000000000894.

Journal of Chemical Health Risks

www.jchr.org

JCHR (2026) 16(2), 1030-1044 | ISSN:2251-6727

[36] M. Infante *et al.*, "Unveiling the Therapeutic Potential of the Second-Generation Incretin Analogs Semaglutide and Tirzepatide in Type 1 Diabetes and Latent Autoimmune Diabetes in Adults," *J. Clin. Med.*, vol. 14, no. 4, p. 1303, Jan. 2025, doi: 10.3390/jcm14041303.

[37] M. Chen *et al.*, "The association between variability of risk factors and complications in type 2 diabetes mellitus: a retrospective study," *Sci. Rep.*, vol. 14, no. 1, p. 6357, Mar. 2024, doi: 10.1038/s41598-024-56777-w.

[38] K. M. Gillespie, "Type 1 diabetes: pathogenesis and prevention," *CMAJ*, vol. 175, no. 2, pp. 165–170, Jul. 2006, doi: 10.1503/cmaj.060244.

[39] S. Demine, A. A. Schiavo, S. Marín-Cañas, P. Marchetti, M. Cnop, and D. L. Eizirik, "Pro-inflammatory cytokines induce cell death, inflammatory responses, and endoplasmic reticulum stress in human iPSC-derived beta cells," *Stem Cell Res. Ther.*, vol. 11, no. 1, p. 7, Jan. 2020, doi: 10.1186/s13287-019-1523-3.

[40] C. Evans-Molina *et al.*, "The heterogeneity of type 1 diabetes: implications for pathogenesis, prevention, and treatment—2024 Diabetes, Diabetes Care, and Diabetologia Expert Forum," *Diabetologia*, vol. 68, no. 9, pp. 1859–1878, Sep. 2025, doi: 10.1007/s00125-025-06462-y.

[41] O. Rolandsson and J. P. Palmer, "Latent autoimmune diabetes in adults (LADA) is dead: long live autoimmune diabetes!," *Diabetologia*, vol. 53, no. 7, pp. 1250–1253, Jul. 2010, doi: 10.1007/s00125-010-1713-0.

[42] C. Evans-Molina *et al.*, "The heterogeneity of type 1 diabetes: implications for pathogenesis, prevention, and treatment—2024 Diabetes, Diabetes Care, and Diabetologia Expert Forum," *Diabetologia*, vol. 68, no. 9, pp. 1859–1878, Sep. 2025, doi: 10.1007/s00125-025-06462-y.

[43] E. Cavalli, G. R. P. Nicoletti, and F. Nicoletti, "A Historical and Epistemological Review of Type 1 Diabetes Mellitus," *J. Clin. Med.*, vol. 14, no. 14, p. 4923, Jan. 2025, doi: 10.3390/jcm14144923.

[44] S. Subramanian and D. Baidal, "The Management of Type 1 Diabetes," in *Endotext*, K. R. Feingold, R. A. Adler, S. F. Ahmed, B. Anawalt, M. R. Blackman, G. Chrousos, E. Corpas, W. W. de Herder, K. Dhatariya, K. Dungan, E. Hamilton, J. Hofland, S. Jan de Beur, S. Kalra, G. Kaltsas, N. Kapoor, M. Kim, C. Koch, P. Kopp, M. Korbonits, C. S. Kovacs, W. Kuohung, B. Laferrère, M. Levy, E. A. McGee, R. McLachlan, R. Muzumdar, J. Purnell, R. Rey, R. Sahay, A. S. Shah, M. A. Sperling, C. A. Stratakis, D. L. Trence, and D. P. Wilson, Eds., South Dartmouth (MA): MDText.com, Inc., 2000. Accessed: Feb. 26, 2026. [Online]. Available: http://www.ncbi.nlm.nih.gov/books/NBK279114/

[45] A. N. Mavrogiannaki and I. N. Migdalis, "Long-acting basal insulin analogs: latest developments and clinical usefulness," *Ther. Adv. Chronic Dis.*, vol. 3, no. 6, pp. 249–257, Nov. 2012, doi: 10.1177/2040622312454158.

[46] Š. Volčanšek, A. Koceva, M. Jensterle, A. Janež, and E. Muzurović, "Amylin: From Mode of Action to Future Clinical Potential in Diabetes and Obesity," *Diabetes Ther.*, vol. 16, no. 6, pp. 1207–1227, Jun. 2025, doi: 10.1007/s13300-025-01733-8.

[47] F. N. U. Sugandh *et al.*, "Advances in the Management of Diabetes Mellitus: A Focus on Personalized Medicine," *Cureus*, vol. 15, Aug. 2023, doi: 10.7759/cureus.43697.

[48] B. Saboo *et al.*, "Reimagining Type 1 Diabetes Care in India: A Three-decade Reflection on Challenges, Innovations, and Opportunities since the Diabetes Control and Complications Trial," *J. Assoc. Physicians India*, vol. 73, no. 12, pp. 71–77, Dec. 2025, doi: 10.59556/japi.73.1258.

[49] M. Ewen *et al.*, "Availability, prices and affordability of self-monitoring blood glucose devices: surveys in six low-income and middle-income countries," *BMJ Public Health*, vol. 3, no. 1, p. e001128, Feb. 2025, doi: 10.1136/bmjph-2024-001128.

[50] R. J. Vitale *et al.*, "An Effective Diabetic Ketoacidosis Prevention Intervention in Children With Type 1 Diabetes," *SAGE Open Nurs.*, vol. 4, p. 2377960818804742, Nov. 2018, doi: 10.1177/2377960818804742.

[51] D. S. L. Gardner *et al.*, "Digital Health Technology in Diabetes Management in the Asia–Pacific Region: A Narrative Review of the Current Scenario and Future Outlook," *Diabetes Ther.*, vol. 16, no. 3, pp. 349–369, Mar. 2025, doi: 10.1007/s13300-025-01692-0.

[52] M. Srinivasan, S. R. Thangaraj, and H. Arzoun, "Gene Therapy - Can it Cure Type 1 Diabetes?," *Cureus*, vol. 13, no. 12, p. e20516, doi: 10.7759/cureus.20516.

[53] I. Cozar-Castellano and A. F. Stewart, "Molecular engineering human hepatocytes into pancreatic beta cells for diabetes therapy," *Proc. Natl. Acad. Sci. U. S. A.*, vol. 102, no. 22, pp. 7781–7782, May 2005, doi: 10.1073/pnas.0503261102.

[54] S. Razi Soofiyani, B. Baradaran, F. Lotfipour, T. Kazemi, and L. Mohammadnejad, "Gene Therapy, Early Promises, Subsequent Problems, and Recent Breakthroughs," *Adv. Pharm. Bull.*, vol. 3, no. 2, pp. 249–255, Dec. 2013, doi: 10.5681/apb.2013.041.

Journal of Chemical Health Risks

www.jchr.org

JCHR (2026) 16(2), 1030-1044 | ISSN:2251-6727

[55] G. A. R. Gonçalves and R. de M. A. Paiva, “Gene therapy: advances, challenges and perspectives,” *Einstein*, vol. 15, no. 3, pp. 369–375, 2017, doi: 10.1590/S1679-45082017RB4024.

[56] L. C. Stene, “Perspectives on prevention of type 1 diabetes and heterogeneities,” *Diabetologia*, vol. 68, no. 10, pp. 2104–2115, Oct. 2025, doi: 10.1007/s00125-025-06512-5.

[57] A. W. Michels, P. A. Gottlieb, B. Nelson, and C. Dayan, “Autoimmune Type 1 Diabetes in the Era of Disease-Modifying Immune Therapy,” *Diabetes Metab. Res. Rev.*, vol. 41, no. 7, p. e70091, Oct. 2025, doi: 10.1002/dmrr.70091.

[58] I. of M. (US) C. on I. B. Outcomes, J. R. Bale, B. J. Stoll, and A. O. Lucas, “Interventions to Reduce the Impact of Birth Defects,” in *Reducing Birth Defects: Meeting the Challenge in the Developing World*, National Academies Press (US), 2003. Accessed: Feb. 27, 2026. [Online]. Available: https://www.ncbi.nlm.nih.gov/books/NBK222083/