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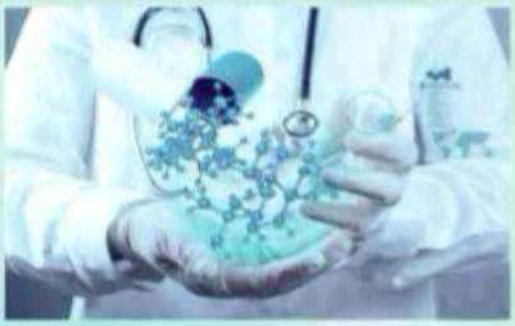

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PEDIATRIC TYPE 1 DIABETES MELLITUS: PATHOPHYSIOLOGY, CLINICAL CHALLENGES, AND MANAGEMENT STRATEGIES

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✓ ***Resume***

Background: Type 1 diabetes mellitus (T1DM) is a chronic autoimmune endocrine disorder that predominantly develops in childhood and adolescence, leading to absolute insulin deficiency and lifelong dependence on insulin therapy. Its global incidence is rising annually by 3–5%, with notable regional variations influenced by genetic susceptibility, environmental triggers, and lifestyle factors.

Objectives: This study aims to provide a comprehensive overview of the epidemiology, pathophysiology, clinical presentation, diagnostic approaches, and management strategies of pediatric T1DM, with an emphasis on current therapeutic innovations and their implications for improving quality of life and reducing complications.

Methods: A structured literature review was conducted using PubMed, Scopus, and Web of Science databases, focusing on peer-reviewed articles, clinical guidelines, and meta-analyses published between 2000 and 2025. Data were extracted on genetic predisposition, autoimmune markers, clinical features, management outcomes, and long-term complications. Special consideration was given to studies evaluating modern technologies such as continuous glucose monitoring (CGM), insulin pump therapy, and hybrid closed-loop systems.

Results: Findings revealed that T1DM incidence is highest in Scandinavian countries and lowest in East Asia, with 20–30% of pediatric patients initially presenting in diabetic ketoacidosis. The most common clinical features included polyuria, polydipsia, weight loss, and fatigue, often accompanied by hyperglycemia and positive pancreatic autoantibodies (GAD65, IA-2, ZnT8). Intensive insulin therapy combined with CGM or insulin pump use significantly improved glycemic control, reduced hypoglycemia, and enhanced patient adherence. However, disparities in access to advanced technologies remain a major limitation, especially in low-resource settings.

Conclusion: Pediatric T1DM is a complex condition with profound medical, psychosocial, and public health implications. Early diagnosis, individualized insulin therapy, family-centered education, and equitable access to modern technologies are essential to optimize clinical outcomes and prevent long-term complications. Addressing disparities in care delivery and integrating psychosocial support into management are critical priorities for improving the lives of children and adolescents living with T1DM.

Keywords: endocrinology, pediatrics, type 1 diabetes mellitus, insulin therapy, autoimmunity, management

PEDIATRIK 1-TUR QANDLI DIABET: PATOFIZIOLOGIYA, KLINIK MUAMMOLAR VA DAVOLASH STRATEGIYALARI

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✓ ***Rezyume***

Kirish: 1-tur qandli diabet (1-TQD) – bu bolalik va o‘smirlik davrida ko‘p uchraydigan surunkali autoimmun endokrin kasallik bo‘lib, u oshqozon osti bezidagi β-hujayralarning yo‘q qilinishi natijasida mutlaq insulin yetishmovchiligi va umrbod insulin terapiyasiga ehtiyojni keltirib chiqaradi. Kasallikning global tarqalishi yiliga 3–5% ga oshib bormoqda, bu jarayonda genetik moyillik, tashqi omillar va turmush tarzi muhim rol o‘ynaydi.

Maqsad: Ushbu maqola pediatrik 1-TQDning epidemiologiyasi, patofiziologiyasi, klinik ko‘rinishlari, tashxis usullari va davolash strategiyalarini yoritish bilan birga zamonaviy terapevtik yangiliklarning hayot sifatini yaxshilash va asoratlarni kamaytirishdagi ahamiyatini tahlil qilishni maqsad qiladi.

Metodlar: 2000–2025 yillarda chop etilgan ilmiy maqolalar, klinik ko‘rsatmalar va meta-tahlillar PubMed, Scopus va Web of Science bazalari orqali tizimli o‘rganildi. Genetik omillar, autoantitanalar, klinik belgilar, davolash natijalari va uzoq muddatli asoratlar haqidagi ma’lumotlar yig‘ildi. Zamonaviy texnologiyalar – doimiy glyukoza monitoringi (CGM), insulin pompasi va yopiq siklli tizimlarga bag‘ishlangan tadqiqotlarga alohida e’tibor qaratildi.

Natijalar: Tadqiqot natijalariga ko‘ra, kasallik eng ko‘p Skandinaviya mamlakatlarida, eng kam esa Sharqiy Osiyoda uchraydi. Bolalarning 20–30% hollarda dastlab diabetik ketoatsidoz bilan murojaat qilgan. Klinik belgilarga poliuriya, polidipsiya, vazn yo‘qotish va charchoq kiradi. Laborator tekshiruvlar giperglikemiya va β-hujayralarga qarshi antitanalarni aniqladi (GAD65, IA-2, ZnT8). Intensiv insulin terapiyasi CGM va insulin pompasi bilan qo‘shib olib borilganda glikemik nazorat yaxshilangan, gipoglikemiya kamaygan va bemorlarning rioya qilishi oshgan. Shunga qaramay, zamonaviy texnologiyalarga kirish imkoniyatidagi tafovutlar asosiy muammo bo‘lib qolmoqda.

Xulosa: Pediatrik 1-TQD murakkab kasallik bo‘lib, u nafaqat tibbiy, balki psixososial va ijtimoiy sog‘liqni saqlash sohalarida ham jiddiy oqibatlarga ega. Erta tashxis, individual insulin terapiyasi, oila markazida olib boriladigan ta’lim va zamonaviy texnologiyalarga teng imkoniyat yaratish klinik natijalarni yaxshilash hamda asoratlarni kamaytirishda muhim ahamiyatga ega. Davolashda tengsizliklarni bartaraf etish va psixososial qo‘llab-quvvatlashni integratsiya qilish pediatrik bemorlarning hayot sifatini oshirish uchun muhim ustuvor yo‘nalishdir.

Kalit so‘zlar: endokrinologiya, pediatriya, 1-tur qandli diabet, insulin terapiyasi, autoimmun jarayon, boshqaruv

ДИАБЕТ 1-ГО ТИПА У ДЕТЕЙ: ПАТОФИЗИОЛОГИЯ, КЛИНИЧЕСКИЕ ПРОБЛЕМЫ И СТРАТЕГИИ ЛЕЧЕНИЯ

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✓ ***Резюме***

Сахарный диабет 1-го типа (СД1) — хроническое аутоиммунное эндокринное заболевание, развивающееся преимущественно в детском и подростковом возрасте. Оно характеризуется разрушением β-клеток поджелудочной железы, что приводит к абсолютной инсулиновой недостаточности и пожизненной зависимости от инсулинотерапии. Глобальная заболеваемость СД1 ежегодно увеличивается на 3–5%, при этом наблюдаются региональные различия, обусловленные генетической предрасположенностью, внешними факторами и образом жизни.

Цель: Цель данного исследования — представить всесторонний обзор эпидемиологии, патофизиологии, клинических проявлений, диагностических методов и стратегий лечения СД1 у детей с акцентом на современные терапевтические инновации и их значение для повышения качества жизни и снижения риска осложнений.

Методы: Был проведён структурированный обзор литературы в базах данных PubMed, Scopus и Web of Science, охватывающий рецензируемые статьи, клинические рекомендации и метаанализы, опубликованные в 2000–2025 гг. Были собраны данные о генетических факторах, аутоантителах, клинических проявлениях, результатах лечения и долгосрочных осложнениях. Особое внимание уделялось исследованиям, оценивающим современные технологии, такие как системы непрерывного мониторинга глюкозы (CGM), инсулиновые помпы и гибридные замкнутые системы.

Результаты: Установлено, что наибольшая заболеваемость СД1 наблюдается в странах Скандинавии, а наименьшая — в Восточной Азии. У 20–30% детей заболевание впервые диагностировалось в состоянии диабетического кетоацидоза. Классическими клиническими проявлениями были полиурия, полидипсия, потеря веса и утомляемость. Лабораторные исследования выявили гипергликемию и наличие аутоантител к β-клеткам (GAD65, IA-2, ZnT8). Интенсивная инсулинотерапия в сочетании с CGM или инсулиновой помпой улучшала гликемический контроль, снижала частоту гипогликемий и повышала приверженность пациентов. Однако неравный доступ к современным технологиям остаётся серьёзным ограничением, особенно в странах с низкими ресурсами.

Заключение: Детский СД1 представляет собой сложное заболевание с серьёзными медицинскими, психосоциальными и общественными последствиями. Ранняя диагностика, индивидуализированная инсулинотерапия, семейное обучение и равный доступ к современным технологиям являются ключевыми факторами для оптимизации клинических исходов и предотвращения осложнений. Ликвидация неравенства в оказании помощи и интеграция психосоциальной поддержки должны стать приоритетом для улучшения качества жизни детей и подростков с СД1.

Ключевые слова: эндокринология, педиатрия, сахарный диабет 1-го типа, инсулинотерапия, аутоиммунные процессы, лечение.

Introduction

Type 1 diabetes mellitus (T1DM) remains a major challenge in pediatric endocrinology, with profound implications for child health, family dynamics, and healthcare systems. Globally, more than 1.1 million children and adolescents are living with T1DM, and the incidence continues to rise by approximately 3–5% annually. Although traditionally considered a disease of childhood, T1DM can present at any age, with peak onset observed between 5–7 years and during puberty.

The pathogenesis of T1DM involves autoimmune-mediated destruction of pancreatic β-cells, leading to insulin deficiency and subsequent hyperglycemia. Both genetic predisposition and environmental triggers contribute to disease development. High-risk HLA genotypes, viral infections, early dietary exposures, and gut microbiome alterations have been implicated as significant factors. The progressive loss of insulin secretion disrupts glucose homeostasis, resulting in acute metabolic disturbances such as diabetic ketoacidosis (DKA) and long-term complications including retinopathy, nephropathy, neuropathy, and cardiovascular disease.

Clinically, children with T1DM often present with polyuria, polydipsia, weight loss, fatigue, and blurred vision. In many cases, delayed diagnosis leads to severe DKA, which remains a leading cause of morbidity and mortality in pediatric patients. Beyond metabolic control, T1DM affects psychosocial well-being, academic performance, and family quality of life, making its management a holistic and lifelong challenge.

Recent advances in diabetes care, including insulin analogs, continuous glucose monitoring (CGM), insulin pump therapy, and closed-loop "artificial pancreas" systems, have transformed the management landscape. However, disparities in access to these innovations highlight the ongoing need for equitable healthcare policies.

Objectives: This study aims to provide a comprehensive overview of the epidemiology, pathophysiology, clinical presentation, diagnostic approaches, and management strategies of pediatric T1DM, with an emphasis on current therapeutic innovations and their implications for improving quality of life and reducing complications.

Materials and methods

A structured literature review was performed using PubMed, Scopus, and Google Scholar to identify relevant studies published between 2000 and 2025. Keywords included *"type 1 diabetes mellitus," "pediatrics," "insulin therapy," "autoimmunity," "continuous glucose monitoring,"* and *"endocrinology."* Guidelines from the International Society for Pediatric and Adolescent Diabetes (ISPAD), the American Diabetes Association (ADA), and the World Health Organization (WHO) were also included.

Selection criteria focused on peer-reviewed studies involving pediatric populations, with emphasis on epidemiology, pathophysiology, diagnostic methods, and management strategies. Exclusion criteria included studies limited to adult populations, case reports without broader clinical significance, and articles with insufficient methodological rigor. Data were extracted and thematically coded into epidemiology, clinical presentation, diagnostic tools, treatment modalities, and outcomes.

Results and Discussion

Epidemiological data indicate a steady increase in T1DM worldwide, with the highest incidence rates observed in Scandinavia and the lowest in East Asia. Genetic predisposition plays a central role, with HLA-DR3/DR4 haplotypes conferring the highest risk. Environmental risk factors such as viral infections (enteroviruses), early exposure to cow's milk proteins, and vitamin D deficiency have been consistently associated with disease onset.

Clinically, most patients presented with classic symptoms of hyperglycemia, while 20–30% were diagnosed following DKA episodes. Laboratory markers included elevated blood glucose, low or undetectable C-peptide, and the presence of autoantibodies (GAD65, IA-2, ZnT8).

Management outcomes demonstrated that intensive insulin therapy—whether via multiple daily injections or continuous subcutaneous insulin infusion (CSII)—significantly improved glycemic control, as reflected by reduced HbA1c levels. The use of CGM and hybrid closed-loop systems further enhanced outcomes by reducing hypoglycemia and improving time-in-range metrics. Educational interventions, psychological support, and family-centered care improved adherence and quality of life.

Discussion:

The findings reinforce the multifactorial etiology of pediatric T1DM, underscoring the interplay between genetics and environment. Early diagnosis remains critical for preventing DKA and minimizing

acute complications. Universal screening for high-risk populations, though not yet standard practice, may reduce diagnostic delays.

Management of pediatric T1DM requires a comprehensive and individualized approach. While insulin therapy remains the cornerstone of treatment, emerging technologies are redefining standards of care. CGM and insulin pumps have demonstrated superiority over conventional therapy, but access remains limited in low- and middle-income countries. Bridging this gap through policy initiatives and financial support is essential to ensure equitable outcomes.

Psychosocial dimensions of T1DM are equally important. Children and adolescents face unique challenges related to self-management, peer interactions, and lifestyle restrictions. Integrating psychological counseling and school-based support systems can alleviate stress and improve long-term adherence.

Long-term outcomes depend heavily on early and sustained glycemic control. The “metabolic memory” phenomenon, demonstrated in landmark studies such as the DCCT/EDIC trial, emphasizes the importance of early intensive therapy in preventing microvascular and macrovascular complications. This evidence supports proactive and aggressive management strategies from the point of diagnosis.

Type 1 diabetes mellitus remains one of the most challenging chronic endocrine disorders in pediatrics, with an incidence that continues to rise worldwide. Its complex pathogenesis, involving genetic predisposition, autoimmune destruction, and environmental triggers, underlines the multifactorial nature of the disease. The findings of this review emphasize that the consequences of T1DM extend far beyond hyperglycemia, encompassing acute metabolic crises such as diabetic ketoacidosis, long-term microvascular and macrovascular complications, and significant psychosocial burdens for both patients and their families.

Early diagnosis and the prompt initiation of intensive insulin therapy are critical in preventing acute complications and establishing optimal glycemic control. The growing use of technological advances, including continuous glucose monitoring, insulin pumps, and hybrid closed-loop systems, represents a major step forward in improving treatment outcomes and quality of life in pediatric patients. However, the unequal distribution of these technologies remains a key barrier to achieving global equity in diabetes care.

Future strategies must integrate not only medical innovations but also family-centered education, psychological support, and public health interventions. Ensuring equitable access to advanced technologies, expanding preventive initiatives, and embedding psychosocial care into treatment protocols will be essential to reduce disparities and improve outcomes. Ultimately, the long-term health and quality of life of children and adolescents living with type 1 diabetes depend on a multidisciplinary, patient-focused approach that bridges clinical care with systemic healthcare policies.

Conclusion

Pediatric T1DM is a complex condition with profound medical, psychosocial, and public health implications. Early diagnosis, individualized insulin therapy, family-centered education, and equitable access to modern technologies are essential to optimize clinical outcomes and prevent long-term complications. Addressing disparities in care delivery and integrating psychosocial support into management are critical priorities for improving the lives of children and adolescents living with T1DM.

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