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Журнал объединяет авторов на территории стран СНГ и помогает обмениваться передовыми научно-образовательными исследованиями.

Содержит научные статьи отечественных и зарубежных авторов по экономическим, техническим, философским, юридическим и другим наукам.

Миссия научно-образовательного электронного журнала «ОБРАЗОВАНИЕ И НАУКА В XXI ВЕКЕ» состоит в поддержке интереса читателей к оригинальным исследованиям и инновационным подходам в различных тематических направлениях, которые способствуют распространению лучшей отечественной и зарубежной практики в интернет пространстве.

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Название публикации: «ARTIFICIAL PANCREAS: ADVANCES IN BIOMEDICAL ENGINEERING»

What is Artificial Pancreas?

The artificial pancreas, also known as automated insulin delivery (AID) system or closed-loop system, is a biomedical device designed to mimic the glucose-regulating function of a healthy pancreas in individuals with diabetes, primarily type 1 diabetes (T1D) and increasingly type 2 diabetes (T2D). It integrates three core components: a continuous glucose monitor (CGM) for real-time blood glucose sensing, an insulin pump for subcutaneous insulin delivery, and a control algorithm that automates insulin dosing based on glucose data and predictive models. This system aims to maintain blood glucose levels within a target range (typically 70-180 mg/dL), reducing the risk of hyperglycemia, hypoglycemia, and long-term complications such as retinopathy, nephropathy, and cardiovascular disease. Advanced variants include dual-hormone systems that incorporate glucagon to counteract low glucose levels, and AI-enhanced algorithms for personalized, adaptive control. Unlike traditional insulin therapy, which requires manual bolusing and adjustments, the artificial pancreas automates basal insulin delivery and, in hybrid systems, provides correction boluses, significantly improving quality of life by minimizing user intervention.

Academic Review: Evolution, Technologies, and Prospects in Diabetes Management

Abstract

The artificial pancreas represents a pivotal advancement in diabetes care, automating insulin delivery through integrated continuous glucose monitoring (CGM), insulin pumps, and sophisticated algorithms to achieve near-physiological glycemic control. This review traces its evolution from early conceptualizations to current hybrid closed-loop (HCL) and advanced HCL (AHCL) systems, evaluates clinical evidence from trials and real-world data, and discusses challenges such as postprandial hyperglycemia and device interoperability. Drawing on publications from 2005–2025, including bibliometric analyses and meta-analyses, it highlights a shift toward AI-driven, fully automated systems and bioartificial approaches. Key metrics like time in range (TIR) demonstrate efficacy, with systems achieving 70-88% TIR in T1D patients. Keywords: artificial pancreas, automated insulin delivery, closed-loop systems, diabetes management, AI integration, bioartificial pancreas.

Introduction

Diabetes mellitus affects over 500 million people globally, with insulin-dependent forms like T1D and advanced T2D requiring precise glucose management to prevent acute and chronic complications. The artificial pancreas addresses the limitations of manual insulin therapy by automating delivery, reducing burden, and improving outcomes. Key advancements include real-time CGM, model predictive control (MPC) algorithms, and integration with wearable devices. This review synthesizes historical developments, current technologies, clinical outcomes, and future directions based on over 20 years of research, emphasizing the transition from sensor-augmented pumps to fully closed-loop systems.

Historical Overview

The concept of an artificial pancreas dates back to the 1970s with early trials of continuous subcutaneous insulin infusion (CSII) using insulin pumps. Significant momentum built in 2005 with the NIH/JDRF workshop on closing the loop, followed by the JDRF Artificial Pancreas Project in 2006. Algorithm research, including MPC, began in the 1990s, while CGM introduction in the early 2000s enabled outpatient systems by 2004-2005. The first U.S. closed-loop human trial occurred in 2007 using the APS platform. Outpatient studies expanded to camp settings in 2013 and home trials, initially with cumbersome laptop-based systems. Pivotal milestones include FDA clearance of the Medtronic 670G in 2016, the first commercial hybrid AID system. By 2025, systems have evolved to include dual-hormone delivery and AI for adaptive control.

Current Technologies

Hybrid Closed-Loop Systems

Hybrid closed-loop (HCL) systems automate basal insulin adjustments while requiring user input for meal boluses. Commercial examples include Medtronic MiniMed 670G/770G/780G (using proportional-integral-derivative and fuzzy logic algorithms), Tandem t:slim X2/Mobi with Control-IQ (MPC-based), Omnipod 5, iLet Bionic Pancreas, and CamAPS FX (approved for pregnancy). These systems achieve TIR of 70-75% (70-180 mg/dL) and hypoglycemia rates of 2-3%. Bedside systems like STG-55 are used in hospitals for perioperative care, achieving TIR >75% and reducing complications.

AI-Driven and Dual-Hormone Systems

AI integration enables adaptive, personalized control. The Smart Dual Hormone Artificial Pancreas (SDHAP) uses SVM/KNN for glycemic classification, ARIMA/GRU for prediction (RMSE 21.75 ± 3.13), and MPC/PI controllers for insulin/glucagon delivery, managing disturbances like exercise. Dual-hormone systems like Inreda AP deliver insulin and glucagon, increasing TIR and reducing hypoglycemia in post-pancreatectomy patients. Event-triggered mechanisms reduce computational load, enhancing battery life.

Bioartificial Pancreas

Bioartificial approaches encapsulate islet cells in biocompatible materials to protect from immune rejection, with innovations in design and encapsulation enhancing viability. These hold promise for long-term insulin independence but face challenges in vascularization and scalability.

Challenges and Future Directions

Challenges include postprandial hyperglycemia, device cost, staff training, and data privacy. CGM lag (5-20 minutes) and interference in critical care limit accuracy. Future directions focus on fully closed-loop (FCL) systems eliminating user announcements, using ultra-fast insulins, adjuvant hormones (e.g., GLP-1 agonists), and AI/ML for real-time learning. Non-mechanical devices like microneedle systems and hardware on FPGAs aim for compactness and personalization. Clinical validation in diverse populations, including T2D and critically ill patients, is essential.

Conclusion

The artificial pancreas has transformed from experimental prototypes to gold-standard therapy, improving TIR and quality of life for diabetes patients. Ongoing AI and bioengineering innovations promise fully automated, personalized systems, reducing reliance on manual interventions and addressing unmet needs in complex scenarios. Multidisciplinary collaboration will be key to overcoming barriers and realizing its full potential.

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