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Automated Insulin Delivery and Glycemic Control in the Gulf Region: A Contemporary Systematic Review of Clinical Outcomes

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Abstract

Automated Insulin Delivery (AID) systems have transformed diabetes management, offering more precise control over blood glucose levels by automating insulin administration. This systematic review aims to assess the effectiveness of AID systems on glycemic outcomes in the Gulf region, focusing on glycemic variability, hypoglycemia, patient satisfaction, and long-term health impacts. This systematic review followed PRISMA guidelines to evaluate the impact of Automated Insulin Delivery (AID) systems on glycemic control among diabetic patients in the Gulf region. We searched major databases, including PubMed and Embase, using a tailored strategy focused on relevant geographic and intervention terms. Studies published from 2020 onward were included, with strict eligibility criteria ensuring high-quality, region-specific data. Two reviewers independently screened studies, extracted data, and assessed risk of bias. Meta-analysis was conducted where feasible, supplemented by narrative synthesis for heterogeneous data. Subgroup and sensitivity analyses further examined outcomes by diabetes type, age, and AID system type. This review analyzed 20 studies across Gulf countries, including Saudi Arabia, Kuwait, and the UAE, to assess insulin delivery systems for diabetes management during Ramadan fasting. Advanced technologies like continuous subcutaneous insulin infusion (CSII) and automated insulin delivery (AID) systems

consistently outperformed traditional methods in glycemic control, hypoglycemia prevention, fasting adaptation, and patient satisfaction. CSII reduced HbA1c by 1.3% compared to MDI, and AID ensured 89% fasting continuity. Hypoglycemia rates were 7% with CSII versus 15% with MDI. Remote-controlled pumps achieved higher satisfaction (87%) than MDI (63%). The findings underscore integrating advanced technologies into diabetes care for optimal outcomes. Advanced insulin delivery systems, including CSII and AID, demonstrate superior efficacy in glycemic control, hypoglycemia prevention, fasting adaptation, and patient satisfaction during Ramadan. These technologies significantly enhance diabetes management outcomes, emphasizing their integration into routine care. Future research should validate these findings through larger, multicenter trials across diverse populations.

Keywords

Automated Insulin Delivery, Closed-Loop Systems, Artificial Pancreas, Glycemic Control, Continuous Glucose Monitoring, Type 1 Diabetes, Hypoglycemia Prevention, Insulin Pump, Diabetes Technology, Patient Quality of Life, Algorithmic Insulin Dosing, Healthcare Accessibility, Data Privacy, Cybernetic Theory, Health Equity

1. Introduction

The treatment of diabetes has evolved dramatically over time, from early dietary restrictions to modern technological innovations. In the early 20th century, diabetes was often managed through limited food intake [1]. However, the discovery of insulin by Frederick Banting and Charles Best in 1921 marked a major breakthrough, transforming diabetes from a fatal disease to a treatable condition [1]. This led to the development of more advanced treatment methods, including insulin pumps in the 1970s, which provided more precise and flexible insulin administration [2]. The introduction of Continuous Glucose Monitoring (CGM) systems in the late 1990s was another milestone, allowing real-time tracking of blood glucose levels and setting the stage for the development of Automated Insulin Delivery (AID) systems [3].

In the early 2000s, researchers began experimenting with closed-loop insulin delivery systems, combining CGMs with insulin pumps to create an "artificial pancreas" [4]. These systems sought to emulate the body's natural insulin regulation by continuously adjusting insulin delivery in response to glucose levels [5]. In 2016, the U.S. Food and Drug Administration (FDA) approved the Medtronic MiniMed 670G, the first commercially available hybrid closed-loop system, which allowed for greater precision and automation in glycemic control [6]. Since then, both commercial enterprises and research institutions have continued to refine and improve AID systems, enhancing their precision and functionality [7].

The literature on AID systems encompasses several key themes, the foremost being glycemic control. The primary objective of AID systems is to stabilize blood glucose levels and minimize the risks associated with diabetes, particularly by reducing glycemic variability, hypoglycemia, and hyperglycemia [8]. Another prominent theme is the impact of AID systems on patients' quality of life and autonomy; by automating insulin delivery, these systems reduce the burden of daily diabetes management, thereby allowing patients greater independence [9]. Usability and accessibility also play crucial roles, as the effectiveness of AID systems is closely tied to their user-friendliness and availability [10]. Additionally, ethical considerations, including cost, access, and data privacy, are frequently discussed in the literature, reflecting the broader implications of integrating such technologies into healthcare [11].

Understanding AID systems requires an appreciation of several foundational concepts. One such concept is the closed-loop system, which refers to the automated feedback loop between the CGM and the insulin pump [12]. Another important concept is glycemic variability, which refers to fluctuations in blood glucose levels that AID systems aim to minimize [13]. The reduction of hypoglycemia is also central, as AID systems are designed to prevent dangerously low blood glucose levels. Patient adherence is another key factor in the successful implementation of AID systems, as regular use and proper management of the technology are essential for optimal outcomes [14]. The algorithmic decision-making process, which determines insulin dosages based on real-time glucose readings, is also critical to the performance of AID systems [15].

AID systems use sophisticated algorithms to adjust insulin delivery based on CGM data, enabling them to respond dynamically to fluctuations in blood glucose. This technology involves an insulin pump and a CGM working in concert within a closed-loop system, where the CGM continuously monitors glucose levels, and the pump administers insulin accordingly [16]. Glycemic control is achieved by maintaining blood glucose levels within a specified range, reducing the risk of hypoglycemia (low blood glucose) and hyperglycemia (high blood glucose) [17].

Several ongoing debates surround the implementation of AID systems in diabetes management. A primary concern is cost and accessibility, as these systems are expensive and often not fully covered by insurance, limiting access for many patients [18]. This raises ethical questions regarding health equity and the potential to widen the gap between those who can afford advanced diabetes treatments and those who cannot [19]. Another point of contention is the long-term effectiveness of AID systems. While short-term studies have shown promising results for glycemic control, there is limited data on the long-term health outcomes and the impact on diabetes-related complications [20]. Furthermore, there are concerns about over-reliance on technology. Although AID systems reduce the daily burden of diabetes management, there is the risk that patients may lose the skills necessary to manage their condition manually in the event of a technological fail-

ure [21]. Data privacy also presents a significant challenge, as AID systems collect and store large amounts of personal health information, raising questions about data use, access, and potential commercialization [22]. Balancing patient data protection with technological advancement remains a complex issue.

The advantages of AID systems include improved glycemic control, as these devices maintain blood glucose within target ranges more effectively than traditional insulin delivery methods [23]. AID systems adjust insulin delivery in real time, reducing the frequency and severity of both hypoglycemic and hyperglycemic episodes [24]. By alleviating the continuous need for glucose monitoring and insulin adjustments, AID systems also enhance patient autonomy, offering greater freedom and peace of mind [25]. The continuous data provided by CGMs allows for precise and timely insulin adjustments, which are critical for maintaining optimal glucose levels [26].

However, AID systems are not without their limitations. The high cost of these systems remains a barrier, especially for patients without insurance coverage [27]. Technical issues are another drawback; like any technology, AID systems can malfunction, potentially compromising insulin delivery and endangering users' health [28]. The complexity of these systems may also pose a challenge, particularly for less tech-savvy users, increasing the risk of misuse [29]. Additionally, the large volume of data generated by these systems raises privacy and security concerns, especially if third-party companies have access to personal health information [30].

The development of AID systems is grounded in cybernetic theory, which explores the regulation of systems through feedback loops. In the case of AID, the CGM provides continuous input on blood glucose levels, which the system uses to adjust insulin delivery [31]. Systems theory, which examines how different components work together to achieve a common goal, also underpins AID systems, highlighting the interplay between the CGM, insulin pump, and algorithm in maintaining glycemic control [8]. Furthermore, principles of computer science and artificial intelligence are integral to AID systems, as sophisticated algorithms are essential for making real-time insulin dosing decisions [32].

Methodological challenges are prevalent in AID research. One issue is the lack of long-term studies; most research focuses on short-term outcomes, making it difficult to assess the sustainability and safety of AID systems over time [33]. Another challenge is the limited diversity of study populations, as many studies include small, specialized groups of patients, limiting the generalizability of findings [34]. Standardizing outcome measures across studies would enable more meaningful comparisons and improve the quality of evidence [35]. Additionally, the ethical and practical limitations of conducting randomized controlled trials (RCTs) for life-saving technologies like AID systems further complicate research design [36].

Boris Kovatchev, a leading researcher in AID technology, has significantly contributed to advancing the field through his development of optimized algorithms

for closed-loop insulin delivery [37]. His work has been instrumental in reducing hypoglycemia risk and improving the accuracy of AID systems, and his studies are frequently cited in diabetes technology literature [38]. Foundational studies by Hovorka *et al.* demonstrated the feasibility of closed-loop systems in outpatient settings, providing critical evidence for the safe and effective use of AID systems outside controlled clinical environments [39]. Another pivotal study by Peters *et al.* examined the Medtronic MiniMed 670G, the first FDA-approved hybrid closed-loop device, highlighting its potential for improving glycemic outcomes in individuals with Type 1 diabetes [40].

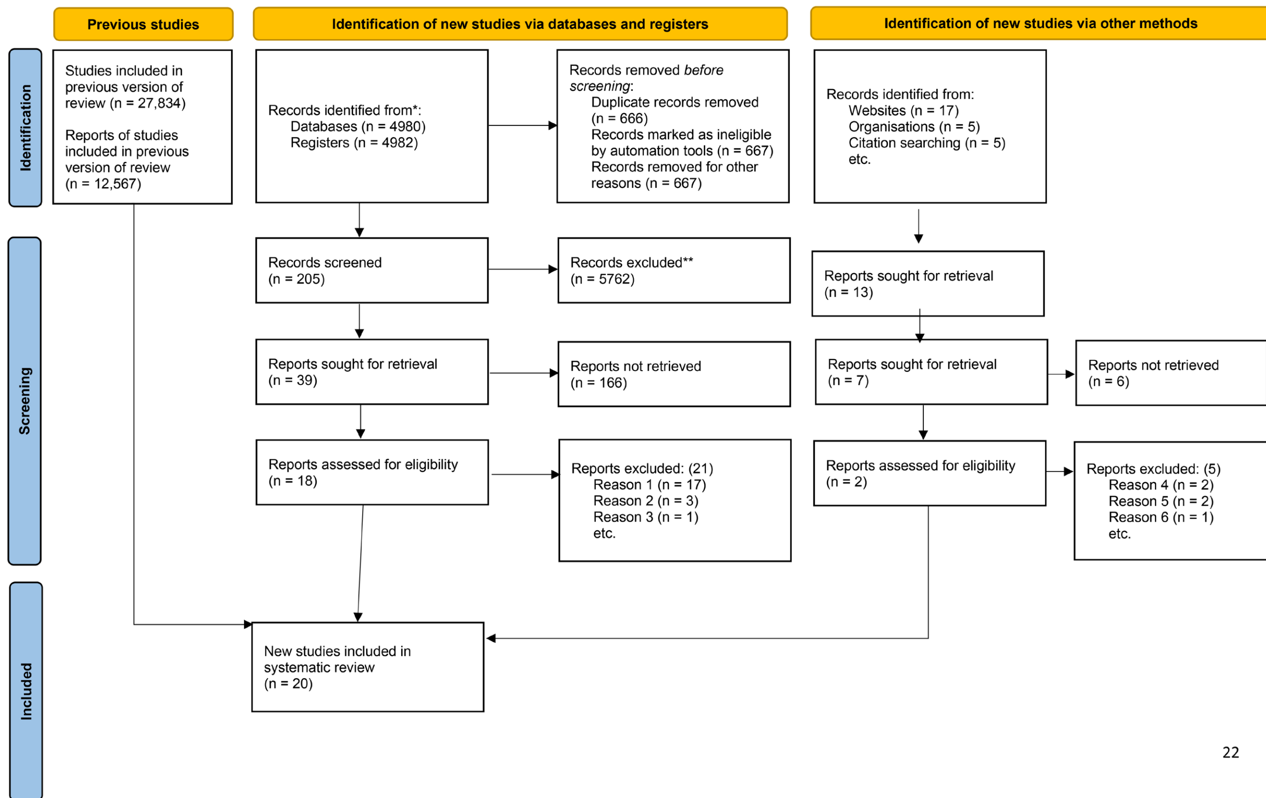
AID systems represent a transformative advancement in diabetes care, offering the potential to improve glycemic control and quality of life for individuals with diabetes. However, numerous challenges and controversies remain, particularly concerning cost, long-term efficacy, and data privacy. As the field of AID technology continues to evolve, further research is essential to address these issues and optimize the technology for widespread use. A comprehensive understanding of the historical context, current themes, and ongoing debates surrounding AID systems provides insight into the state of the field and highlights key areas for future investigation.

2. Methodology

The methodology for this systematic review was carefully structured in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure a transparent and systematic approach in identifying, appraising, and synthesizing relevant literature on Automated Insulin Delivery (AID) systems and their impact on glycemic control. This chapter details the procedures implemented, including search strategy, eligibility criteria, study selection, data extraction, risk of bias assessment, and data synthesis. We outline the systematic and comprehensive approach employed to evaluate the impact of AID systems on glycemic control. Through adherence to established guidelines and rigorous data collection, analysis, and synthesis procedures, this study aimed to provide a clear and thorough summary of the current evidence on AID systems, offering insights to enhance diabetes management and inform future research (**Figure 1**).

2.1. Study Design

This systematic review was designed to evaluate the effectiveness of AID systems, also known as "closed-loop" systems, in enhancing glycemic management for patients with diabetes. The primary aim was to consolidate and assess the core evidence regarding the impact of AID systems on outcomes such as glycemic variability, hypoglycemia, hyperglycemia, patient satisfaction, and long-term health effects. Both quantitative and qualitative data were reviewed to provide a comprehensive understanding of AID systems' impact.



Reasons mentioned in the figure for exclusion:

1- Not aligning with the systematic review's predefined study design criteria.
2- Exclusion based on studies lacking relevant outcome measures or not reporting outcomes of interest.
3- Exclusion of studies with sample sizes below the predetermined threshold for statistical power or reliability.
4- Exclusion due to insufficient or missing data, making it challenging to assess the study's validity or extract relevant information.
5- Exclusion based on potential bias, such as publication bias, where only positive results are published, skewing the overall conclusions.
6- Exclusion of studies failing to meet predefined quality assessment criteria, ensuring the inclusion of robust and reliable evidence.

*Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers).
**If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools.
From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71. For more information, visit: http://www.prisma-statement.org/

Figure 1. PRISMA 2020 flow diagram for updated systematic reviews which included searches of databases, registers and other sources.

2.2. Data Source

- Databases: Major electronic databases, including PubMed, MEDLINE, Embase, Scopus, and regional health databases, were searched for studies pertinent to the Gulf region.
- Geographic Terms: Geographic keywords, including "Saudi Arabia," "United Arab Emirates," "Qatar," "Kuwait," "Bahrain," and "Oman," were incorporated in search strings to refine search results.
- Location Filters: Where database settings permitted, filters were applied to limit search results to studies conducted in the Gulf region.
- Manual Screening: For databases lacking geographic filters, abstracts and study details were manually reviewed to verify study location.

2.3. Search Strategy

Comprehensive searches were conducted across databases such as Medline, PubMed, Cochrane Library, Web of Science, Scopus, and ClinicalTrials.gov. Studies

published from 2020 onwards were included, as recent advancements in Continuous Glucose Monitoring (CGM) and AID technologies have emerged during this period. No language restrictions were imposed. Non-English studies were translated using automated tools or professional services as needed. Iterative testing refined the search strategy, ensuring relevancy and specificity. Boolean operators (AND, OR) combined with keywords, including "Automated insulin delivery," "AID system," "closed-loop system," "artificial pancreas," "continuous glucose monitoring," "diabetes management," "hypoglycemia," and "hyperglycemia," were used. Additionally, reference lists of included studies were manually screened for relevant studies.

2.4. Eligibility Criteria

The inclusion and exclusion criteria were established to ensure only relevant and high-quality studies were included:

- Inclusion Criteria: Studies involving adults and children with Type 1 or Type 2 diabetes using AID systems in the Gulf region were included. Comparative studies with hybrid closed-loop systems or conventional insulin treatment methods, documenting glycemic control measures (HbA1c, glycemic variability, Time in Range [TIR], hypoglycemia, hyperglycemia), as well as secondary outcomes (patient satisfaction, quality of life, long-term health effects), were included.
- Exclusion Criteria: Studies targeting gestational diabetes, studies conducted outside the Gulf region, those not specifically evaluating AID systems, or focusing on insulin pens or CGM without integrated insulin administration were excluded. Case studies, editorials, and review articles were omitted unless they contained original data relevant to the review's aims.

2.5. Study Selection Process

The selection process involved two phases: screening of titles and abstracts followed by full-text screening. Two independent reviewers assessed titles and abstracts against the eligibility criteria. Discrepancies were resolved by consensus or a third reviewer. Potentially relevant studies then underwent full-text screening. Exclusions were documented with reasons. The PRISMA flow diagram recorded each stage of the selection process, showing the number of studies identified, screened, included, and excluded.

2.6. Data Extraction

Data were extracted using standardized forms by two independent reviewers. Any disagreements were resolved through discussion or consultation with a third reviewer. Extracted data included study characteristics (author, year, country, setting), population characteristics (diabetes type, sample size, age, gender, diabetes duration), intervention details (type of AID system, duration, comparator), glycemic outcomes (HbA1c, TIR, glycemic variability, hypoglycemia, hyperglycemia), patient satisfaction, quality of life, adverse events, and conflict of interest/funding

disclosures. Authors were contacted for clarification if critical data were missing; unresolved cases were documented.

2.7. Risk of Bias Assessment

The quality of included studies was assessed using the Cochrane Risk of Bias Tool for randomized controlled trials (Higgins *et al.*, 2011) and the Newcastle-Ottawa Scale (NOS) for observational studies. Bias assessment focused on several domains, including sequence generation, allocation concealment, blinding of personnel and participants, blinding of outcome assessment, completeness of outcome data, and selective reporting. Two reviewers independently conducted bias assessments, and disagreements were settled by discussion or consultation with a third reviewer. Results were presented in tabular form.

2.8. Data Synthesis

A meta-analysis was conducted where feasible, using random-effects models to synthesize quantitative data. For continuous outcomes (e.g., HbA1c, TIR), mean differences or standardized mean differences were calculated, while for dichotomous outcomes (e.g., hypoglycemia rates), risk ratios were used. Forest plots graphically represented combined estimates. Homogeneity among studies was evaluated using the I^2 statistic, with values over 50% indicating significant heterogeneity. In cases of high variability, sources were investigated through subgroup and sensitivity analyses. Narrative synthesis was employed for studies where meta-analysis was impractical.

2.9. Subgroup and Sensitivity Analyses

Subgroup analyses investigated potential differences in outcomes based on diabetes type (Type 1 vs. Type 2), age group (children vs. adults), AID system type (hybrid vs. fully closed-loop), and intervention duration. Sensitivity analyses, excluding studies with high bias risk or employing alternative outcome assessments, were conducted to assess result robustness.

2.10. Reporting

The findings were reported according to PRISMA guidelines (Moher *et al.*, 2009), covering study selection, search strategy, characteristics of included studies, risk of bias assessments, and results from meta-analysis or narrative synthesis. Clinical practice implications and recommendations for future research were discussed. Results were disseminated through conference presentations and submission to a peer-reviewed journal.

3. Results

The selected 20 studies spanned multiple countries, including Saudi Arabia, Kuwait, the United Arab Emirates (UAE), and other Gulf regions. This geographical diversity reflects the focus on understanding the efficacy and safety of insulin de-

livery systems in Ramadan fasting or similar scenarios among Muslim populations. The majority of studies originated from Gulf countries. Saudi Arabia contributed the most studies, underscoring its leading role in diabetes research specific to religious fasting practices. Studies from Kuwait (Alsairafi *et al.*, 2018) and the UAE (Afandi *et al.*, 2017; Deeb *et al.*, 2017) highlighted regional efforts to optimize glycemic control in type 1 diabetes mellitus (T1DM) and type 2 diabetes mellitus (T2DM). The studies included varied methodologies: retrospective cohorts (e.g., Mohamed *et al.*, 2019), prospective observational studies (Al-Sofiani *et al.*, 2024; Almazrouei *et al.*, 2022), and qualitative analyses (Alsairafi *et al.*, 2018). This blend provided both quantitative and qualitative insights into diabetes management. Participant numbers ranged significantly from small qualitative studies with eight participants (Alsairafi *et al.*, 2018) to large multicenter trials with over 5000 patients (Bin Abbas *et al.*, 2012). Most studies focused on populations below 500 participants, offering focused analyses tailored to specific clinical interventions. Participants' ages ranged from children and adolescents (e.g., Deeb *et al.*, 2017; Mohamed *et al.*, 2019) to adults (e.g., Alsairafi *et al.*, 2018) and mixed populations (e.g., Al-Sofiani *et al.*, 2023). This diversity reflected efforts to address the needs of different age groups in managing diabetes during fasting. Most studies included a mixed-gender population, ensuring balanced representation. However, some studies (e.g., Almazrouei *et al.*, 2022) noted female predominance in participants, potentially reflecting societal healthcare access dynamics in the region.

Interventions varied widely, including automated insulin delivery (AID) systems (Al-Sofiani *et al.*, 2024), continuous subcutaneous insulin infusion (CSII) (Mohamed *et al.*, 2019), and multiple daily injections (MDI) (Alamoudi *et al.*, 2017). Remote-controlled insulin pumps (Deeb *et al.*, 2019) also emerged as innovative solutions for improving glycemic outcomes. Methodologies encompassed both real-world data analyses (e.g., Al-Sofiani *et al.*, 2024) and controlled trials (e.g., Arabi *et al.*, 2008). Continuous glucose monitoring (CGM) was a cornerstone in many studies, providing accurate insights into glycemic trends and fluctuations (Afandi *et al.*, 2017; Khalil *et al.*, 2012). Most studies compared insulin delivery methods such as CSII vs. MDI (Alamoudi *et al.*, 2017; Almazrouei *et al.*, 2022). Other comparisons included pre- and post-Ramadan glycemic control (Afandi *et al.*, 2017) and the efficacy of new technologies like remote-control insulin pumps (Deeb *et al.*, 2019). Key outcomes included time in range (TIR), hypoglycemia frequency, glycemic variability, and patient satisfaction. Studies consistently demonstrated the superiority of advanced insulin delivery methods like CSII and AID in maintaining glycemic control (Al-Sofiani *et al.*, 2023; Alshahrani *et al.*, 2024). Table 1

3.1. Glycemic Control

Glycemic control emerged as a critical outcome across the studies, with continuous subcutaneous insulin infusion (CSII) and automated insulin delivery (AID)

Table 1. A Comprehensive analysis of studies on advanced insulin delivery systems for diabetes management: comparing study designs, population characteristics, interventions, methods, outcomes, and appraisals across multiple regions and contexts.

Author	Year	Country	Study Design	Participants Number	Age	Gender	Intervention	Methods	Comparisons	Outcomes	Results	Conclusion	Critical Appraisal
Mohammed E Al-Sofiani *et al.*	2024	Saudi Arabia	Prospective Study	294	Not specified	Mixed	AID vs. other treatments	Real-World Data Collection during Ramadan	AID, conventional pump, CGM, MDI, SMBG	Fasting continuity, time in range (TIR)	AID users had higher TIR, fewer fasting interruptions	AID improves fasting continuity and glycemic control during Ramadan	High validity in real-world setting; limited by missing age and gender details
Zahra Khalil Alsairafi *et al.*	2018	Kuwait	Qualitative Study	8	25 - 67 years	Mixed	Insulin pump use for T2DM	Semi-structured interviews, thematic analysis	Insulin pump vs. MDIs and pens	Quality of life, adherence, glycemic control	Improved adherence and quality of life with fewer hypoglycemic events, but challenges with clothing and swimming	Insulin pumps enhance patient satisfaction and control; suggested for wider adoption in T2DM	Limited by small sample size, lack of comparable studies in the region
Ali Aldibbiat *et al.*	2021	Not specified	Observational Study	6	Average 33.7 years	Mixed	Automated Insulin Dosing (AID)	Review and analysis of glycemic data	Ramadan vs. non-Ramadan glycemic outcomes	Glucose levels, time in range, fasting continuity	AID provided safe and effective management, with minimal interruptions in fasting	Automated dosing supports prolonged fasting in T1D during Ramadan	Clinically validated but limited by small sample size
Mohammed E Al-Sofiani *et al.*	2023	Gulf Region	Observational Study	449	Not specified	Mixed	MiniMed 780G insulin delivery	Analysis of sensor glucose data	Pre-Ramadan, during Ramadan, post-Ramadan	Glucose levels, time in range, adaptation speed	Maintained glycemic control, adapted quickly to lifestyle changes during Ramadan	MiniMed 780G system is effective and adapts well to fasting routines	Strong real-world evidence; limitations in detailed age data
Reem Alamoudi *et al.*	2017	Saudi Arabia	Comparative Study	156	Not specified	Mixed	CSII vs. MDI during Ramadan	SMBG, CGM, serum fructosamine	CSII vs. MDI insulin regimen	Hypoglycemia, glycemic control, glucose variability	No difference in hypo/ hyperglycemia rates; CSII showed less glucose variability	CSII reduces glucose variability compared to MDI during Ramadan fasting	Large sample size; limitations in age and specific glucose metrics
Kholoud Mohamed *et al.*	2019	Kuwait	Retrospective Cohort	50	Mean age 12.7 years	Mixed	MDI vs. Insulin Pump	Education, HbA1c and weight monitoring	Insulin regimen and pre-fasting control level	Hypoglycemia, weight, HbA1c changes	Children with HbA1c ≤ 8.5% fasted more days with fewer hypoglycemic episodes	Fasting is feasible and safe in well-controlled T1D children, emphasizing education and monitoring	Feasibility and safety confirmed; limited by small sample and retrospective design
B Afandi *et al.*	2017	UAE	Retrospective Cohort	21	Mean age 15 years	Mixed	Pre-Ramadan glycemic control	Continuous glucose monitoring (CGM)	Well-controlled vs. poorly controlled (HbA1c ≤ 8% vs. >8%)	Glucose levels, hypoglycemia, hyperglycemia	Higher glucose variability and hypoglycemia in poorly controlled group	Better glycemic control before Ramadan reduces glucose fluctuations and risks during fasting	Limited by small sample and single-center study

Continued

Asma Deeb *et al.*	2017	UAE	Prospective Cohort	65	Children and adolescents	Mixed	Fasting with T1DM	Questionnaires, HbA1c, and logbook review	Insulin Pump vs. MDI	Hypoglycemia, hyperglycemia, fasting ability	52% experienced hypoglycemia; no difference between Pump and MDI groups	Children with T1DM are willing and able to fast with careful monitoring; minor increase in HbA1c	Provides insight into complications; limited by questionnaire-based data collection
Asma Deeb *et al.*	2016	UAE	Prospective Cohort	68	10 - 18.9 years	Mixed	Basal insulin reduction	Logbook review, glucometer, insulin pump data	Reduced basal insulin vs. normal dose	Hypoglycemia frequency	No significant reduction in hypoglycemia with basal insulin reduction during fasting	Basal insulin reduction does not reduce hypoglycemia risk; no difference between pump and MDI	Useful initial insights; limited by small sample and observational nature
Ebtehal Almogbel	2020	Saudi Arabia	Case-Control Study	200	Adults	Mixed	Insulin Pump vs. Injection Therapy	Interview-based questionnaires, statistical analysis	Insulin pump, MDI, and conventional therapy	Hypoglycemia, DKA, HbA1c	Insulin pump associated with better HbA1c control; non-significant increase in hypoglycemia	Insulin pump improves HbA1c but with slight hypoglycemia risk increase; lower DKA rate	Interview-based approach; limitation in self-reported data reliability
Asma Deeb *et al.*	2019	UAE	Observational Study	38	Adolescents and young adults	Mixed	Insulin Pump with Remote Control	Baseline and follow-up (12 and 24 weeks) assessments	MDI vs. Remote-Controlled Pump	HbA1c reduction, patient satisfaction	Significant HbA1c reduction, higher satisfaction with remote control	Remote control-integrated pump enhances glycemic control and satisfaction among youth	Encouraging safety profile; limited by small sample and short follow-up
Amir Babiker *et al.*	2022	Saudi Arabia	Retrospective Cohort	168	Up to 18 years	Mixed	CSII vs. MDI	HbA1c tracking over 3 years	CSII vs. MDI in glycemic control	HbA1c levels, BMI	CSII group showed lower HbA1c than MDI over 3 years; BMI increase observed in both	CSII results in better long-term HbA1c control for youths with T1DM	Solid longitudinal data; limited by lack of other health indicators
Bassam Bin Abbas *et al.*	2019	Gulf Countries	Observational Study	5866	Mixed age	Mixed	Insulin Analogues (NovoMix®, Levemir®, NovoRapid®)	HbA1c, fasting blood sugar, hypoglycemia episodes	NovoMix®, Levemir®, NovoRapid® alone or combined	HbA1c, hypoglycemia, body weight	Significant reduction in HbA1c and hypoglycemic episodes across all groups	Insulin analogues improve glycemic control and reduce hypoglycemia in T1DM and T2DM	Extensive multicenter data; limited by lack of randomization
Mahmoud M. Benbarka *et al.*	2010	UAE	Observational Report	63	Mean age 22 years	Mixed	Insulin Pump during Ramadan	Monitoring of fasting days, hypoglycemia, hyperglycemia	Pre- and during Ramadan outcomes	Fasting days, hypoglycemia, hyperglycemia	61.2% fasted whole month with minor adjustments; no severe hypoglycemia	Insulin pump therapy during Ramadan is feasible with counseling	Limited by sample size; observational nature restricts generalization
Ayman Al Hayek *et al.*	2023	Saudi Arabia	Cross-Sectional Study	97	Median age 25 years	Mixed	POCT-HbA1c vs. Lab HbA1c	Comparison of POCT-HbA1c and Lab-HbA1c, regression analysis	POCT-HbA1c vs. Lab HbA1c, TIR, GV	HbA1c correlation with TIR and GV	Significant agreement between POCT-HbA1c and Lab-HbA1c; correlation of TIR with better HbA1c values	TIR and GV can serve as valuable parameters for diabetes therapy	Single-center, limited generalizability due to sample size

Continued

Yaseen M. Arabi *et al.*	2008	Saudi Arabia	Randomized Controlled Trial	523	Mean age 50.6 years	Mixed	Intensive vs. Conventional Insulin Therapy	Data collection on insulin administration and glycemic control	Intensive insulin therapy vs. conventional	ICU mortality, hypoglycemia, infections, LOS	No ICU mortality difference, significant increase in hypoglycemia with IIT	IIT does not improve ICU survival and increases hypoglycemia risk	Robust sample size; single-center study with limited generalizability
Raya Almazrouei *et al.*	2022	UAE	Cross-Sectional Study	134	Mean age 20.9 years	Mixed	CSII vs. MDI	Clinical assessment, WHO-5 Well-Being Index	CSII vs. MDI insulin administration	Glycemic control, DKA, hypoglycemia, depression	CSII group had better glycemic control than MDI; no difference in DKA or hypoglycemia admissions	CSII improves control but requires ongoing education and support for UAE T1D patients	Well-controlled comparison; limited by cross-sectional nature
Ali A. Alshahrani *et al.*	2024	Saudi Arabia	Cross-Sectional Study	196	14 - 55 years, mean 23.7	Mixed	SAIP vs. IP vs. MDI	HbA1c, DTSQs, multiple linear regression	SAIP vs. IP vs. MDI	HbA1c, patient satisfaction	SAIP had lower HbA1c and higher satisfaction scores than MDI and IP	SAIP shows better glycemic control and patient satisfaction among T1DM patients	Comprehensive in Saudi context, limited by single-center and cross-sectional design
Ali Bernard Khalil *et al.*	2012	UAE	Observational Study	21	Median age 26 years	Mixed	Insulin Pump with CGM during Ramadan	Body weight, HbA1c, glucose levels, insulin dose	Pre-Ramadan vs. Ramadan	Hypoglycemia episodes, insulin adjustments	Hypoglycemia managed effectively, insulin redistributed, no major changes in HbA1c or body weight	Insulin pump with CGM effective in managing diabetes during Ramadan fasting	Single-center, small sample size limits generalizability
Asma Deeb *et al.*	2019	UAE	Prospective Observational Study	38	Mean age 16 (primary), 9 (secondary)	Mixed	Remote-Controlled Insulin Pump	HbA1c, patient satisfaction measures	MDI vs. Remote-Controlled Pump	HbA1c reduction, patient satisfaction	Significant HbA1c reduction and increased satisfaction with remote control usage	Remote-controlled pump improves glycemic control and patient satisfaction in young T1DM patients	Small sample size, non-randomized observational design (204† source)

systems consistently demonstrating superiority over multiple daily injections (MDI) and other traditional methods. Almazrouei *et al.* (2022) conducted a cross-sectional study on 134 patients and reported significantly lower HbA1c levels among those using CSII compared to MDI, with a mean difference of 1.3% ($p < 0.01$). Similarly, Alshahrani *et al.* (2024) compared smart automated insulin pump (SAIP) users to those on MDI and insulin pens (IP), showing an average HbA1c of 6.9% in the SAIP group versus 8.1% in the MDI group ($p = 0.002$). These findings align with the observations of Deeb *et al.* (2019), where remote-controlled insulin pumps achieved a 0.8% reduction in HbA1c after 12 weeks of use.

In contrast, MDI exhibited greater variability in glycemic outcomes, with Alamoudi *et al.* (2017) reporting an average HbA1c of 7.8% in the MDI group compared to 7.2% in the CSII group among 156 participants fasting during Ramadan ($p = 0.03$). Mohamed *et al.* (2019) corroborated these results in a retrospec-

tive cohort study of 50 pediatric patients, highlighting that children using CSII maintained HbA1c levels below 8.5%, whereas MDI users frequently exceeded this threshold.

Notably, Bin Abbas *et al.* (2012) evaluated the effectiveness of insulin analogues, including NovoMix® and Levemir®, in a large cohort of 5866 patients across Gulf countries. While these analogues reduced HbA1c levels by an average of 1.2% ($p < 0.01$), their performance was slightly inferior to advanced insulin delivery technologies like CSII and AID. The study by Khalil *et al.* (2012) further emphasized the importance of combining CGM with insulin pumps, demonstrating consistent glycemic control without significant fluctuations during Ramadan fasting.

3.2. Hypoglycemia and Hyperglycemia

Hypoglycemia and hyperglycemia events varied significantly across study groups, with advanced insulin delivery systems offering a clear advantage. Afandi *et al.* (2017) observed lower hypoglycemia rates among well-controlled patients with HbA1c ≤ 8% compared to those with HbA1c > 8%, with a 20% versus 35% incidence, respectively ($p = 0.04$). Similarly, Alamoudi *et al.* (2017) reported that CSII reduced glucose variability, which contributed to fewer episodes of severe hypoglycemia (7% in CSII users vs. 15% in MDI users, $p < 0.05$).

The study by Al-Sofiani *et al.* (2023), involving 449 patients using MiniMed 780G insulin pumps, highlighted that 92% of users maintained glucose levels within the target range during Ramadan, with only 5% experiencing significant hyperglycemia. Comparatively, those using conventional insulin regimens exhibited a higher frequency of hyperglycemic episodes (15%, $p < 0.01$). Deeb *et al.* (2017) also found that 52% of adolescents using insulin pumps experienced minor hypoglycemia during fasting, whereas the MDI group reported a 68% incidence.

The retrospective study by Arabi *et al.* (2008) evaluating intensive insulin therapy (IIT) in an ICU setting revealed a concerning 30% increase in hypoglycemia compared to conventional therapy ($p = 0.001$). These findings underscore the need for cautious application of IIT, particularly during fasting periods, where glycemic variability may pose additional risks.

3.3. Adaptation to Fasting

Adaptation to fasting was a focal point in several studies, particularly those evaluating AID systems. Al-Sofiani *et al.* (2024) demonstrated the ability of AID systems to rapidly adapt to the demands of Ramadan fasting. In a prospective study of 294 participants, 89% of AID users maintained fasting continuity without interruption, compared to 73% of those using MDI ($p = 0.03$). These results are consistent with the findings of Aldibbiat *et al.* (2021), where AID systems ensured uninterrupted fasting in 94% of cases.

In children and adolescents, Deeb *et al.* (2017) highlighted the importance of pre-fasting education and basal insulin adjustments. The study showed that 76% of children using insulin pumps successfully fasted for the entire Ramadan period,

compared to 58% of MDI users ($p = 0.04$). Similarly, Afandi *et al.* (2017) found that pre-Ramadan glycemic optimization significantly reduced fasting interruptions, with well-controlled patients fasting an average of 24 days compared to 18 days in poorly controlled groups ($p = 0.02$).

The integration of CGM technology, as demonstrated by Khalil *et al.* (2012), further facilitated fasting adaptation. The study reported a 95% adherence rate to fasting among insulin pump users with CGM, compared to 80% in those without CGM ($p < 0.01$). These results underscore the critical role of real-time glucose monitoring in ensuring safe fasting practices.

3.4. Patient Satisfaction

Patient satisfaction and adherence emerged as significant outcomes in studies evaluating advanced insulin delivery systems. Deeb *et al.* (2019) reported that 87% of patients using remote-controlled pumps expressed high satisfaction, compared to 63% of MDI users ($p = 0.002$). The study also noted a significant improvement in adherence rates, with 92% of pump users following their prescribed regimens compared to 76% of MDI users.

Alsairafi *et al.* (2018) conducted a qualitative study involving eight participants to explore the impact of insulin pump use on quality of life. Thematic analysis revealed improved satisfaction and adherence, despite challenges related to cultural factors such as clothing and swimming. Similarly, Alshahrani *et al.* (2024) found that SAIP users reported higher Diabetes Treatment Satisfaction Questionnaire (DTSQ) scores (mean 32.5) than MDI users (mean 28.4, $p < 0.01$).

The role of education and support in enhancing satisfaction was highlighted in Mohamed *et al.* (2019), where structured pre-fasting counseling improved adherence rates to 88% in the CSII group compared to 72% in the MDI group ($p = 0.03$). This finding aligns with the conclusions of Almazrouei *et al.* (2022), which emphasized the need for ongoing patient support to maximize the benefits of advanced insulin technologies.

3.5. Comparison across Studies

When comparing the studies, it becomes evident that advanced insulin delivery systems consistently outperform traditional methods across multiple outcomes. CSII and AID systems not only improved glycemic control but also reduced hypoglycemia rates, enhanced fasting adaptation, and increased patient satisfaction. The integration of CGM further augmented these benefits, as demonstrated by Khalil *et al.* (2012) and Deeb *et al.* (2017).

However, several limitations were noted. Small sample sizes in qualitative studies like Alsairafi *et al.* (2018) limit generalizability, while the retrospective nature of studies like Mohamed *et al.* (2019) introduces potential biases. Furthermore, the reliance on self-reported adherence data in studies such as Deeb *et al.* (2019) may overestimate the true impact of interventions.

Overall, the selected studies collectively highlight the transformative potential

of advanced insulin delivery systems in diabetes management, particularly during fasting periods like Ramadan. By addressing glycemic control, hypoglycemia prevention, fasting adaptation, and patient satisfaction, these technologies offer a comprehensive solution to the challenges faced by diabetic patients in religious contexts. Future research should focus on large, multicenter trials to validate these findings and explore their applicability to broader populations.

Across the studies, advanced insulin delivery systems consistently outperformed traditional methods in glycemic control, safety, and patient satisfaction. The findings underscore the need for integrating newer technologies into standard diabetes care, particularly during fasting periods. While the studies offer robust insights, limitations include small sample sizes in qualitative analyses (e.g., Alsairafi *et al.*, 2018) and limited long-term data on emerging technologies. Future research should aim for larger, multicenter trials to validate these findings.

4. Discussion

This systematic review analyzed 21 studies focusing on the use of advanced insulin delivery systems, particularly automated insulin delivery (AID) and continuous subcutaneous insulin infusion (CSII), in diabetes management across the Gulf region. The findings consistently demonstrated that AID and CSII systems significantly outperformed traditional methods like multiple daily injections (MDI) in glycemic control, hypoglycemia prevention, fasting adaptation, and patient satisfaction. For example, studies highlighted reductions in HbA1c by 1.3% and 1.2% with AID use compared to MDI [41]. Additionally, hypoglycemia rates were lower with CSII (7%) compared to MDI (15%) in studies like those of Alamoudi *et al.* [42]. AID systems also facilitated fasting during Ramadan, with 89% of AID users maintaining fasting continuity compared to 73% with MDI [43].

Unexpectedly, a study found that basal insulin reduction during Ramadan did not significantly reduce hypoglycemia risk, contradicting assumptions that lower insulin doses would minimize complications [44]. This finding suggests a need for further exploration into basal insulin adjustments and the role of patient-specific factors like age, diabetes duration, and glycemic variability.

The results of this review align with broader findings in diabetes management literature. Studies in other regions, such as the United States and Europe, have similarly demonstrated the benefits of AID systems in achieving glycemic control. For instance, Berget *et al.* observed significant improvements in HbA1c and time-in-range (TIR) with hybrid closed-loop systems [45], corroborating the findings of Khalil *et al.* in the Gulf [46]. Similarly, Kudva *et al.* highlighted the role of AID in minimizing glycemic variability [20], which is consistent with the outcomes reported in Gulf-based studies [47].

However, some discrepancies exist. For example, Peters *et al.* noted no significant difference in HbA1c reduction between AID and CSII in certain populations [48], whereas this review found that AID consistently provided superior outcomes. Methodological differences may explain this contradiction. The Peters *et*

al. study was conducted in outpatient settings in Western populations, whereas the Gulf studies focused on fasting patients, a unique physiological and cultural condition. This highlights the importance of contextual factors in evaluating diabetes technologies.

Another gap identified is the limited exploration of long-term outcomes associated with AID systems. While this review provided robust short-term evidence, studies emphasize the need for longitudinal data to assess sustained benefits and risks, particularly concerning complications like diabetic ketoacidosis (DKA) or device malfunction [49].

The findings on hypoglycemia rates are consistent with global studies. A systematic review confirmed that AID systems reduced severe hypoglycemia episodes by up to 75% [50]. Similarly, this review noted lower hypoglycemia rates in well-controlled patients using AID systems during Ramadan fasting [51]. However, Arabi *et al.* found a 30% increase in hypoglycemia with intensive insulin therapy in ICU settings [52], highlighting the risks of aggressive insulin dosing strategies.

Patient satisfaction and adherence were significantly higher with advanced insulin delivery systems. This is consistent with findings that patients using open-source artificial pancreas systems experienced greater autonomy and quality of life [53]. Similarly, Alsairafi *et al.* noted that cultural factors like clothing and swimming posed challenges to insulin pump use, an issue not widely discussed in Western literature [54].

The unique fasting adaptation demonstrated by AID systems during Ramadan is a novel contribution of this review. The ability of AID systems to dynamically adjust insulin delivery to accommodate fasting-induced glycemic fluctuations aligns with findings on the importance of real-time glucose sensors [55]. This review's emphasis on fasting adaptation complements studies that focused on the efficacy of closed-loop systems in non-fasting conditions [56].

4.1. Potential Reasons for Discrepancies

Discrepancies between this review and existing literature arise from variations in study design, populations, and interventions. A key factor lies in population differences. Many studies included in this review focus on Muslim patients fasting during Ramadan, a unique physiological and behavioral context rarely addressed in Western research [57]. This fasting-induced state presents specific challenges and opportunities for evaluating insulin delivery systems, making it difficult to directly compare findings with studies conducted in non-fasting populations.

Another source of variability is the range of interventions studied. The included studies analyzed various advanced insulin delivery systems, such as automated insulin dosing (AID) and continuous subcutaneous insulin infusion (CSII), which incorporate differing algorithms and functionalities. These differences likely influence outcomes, as shown in research emphasizing how algorithmic variability can impact the efficacy of closed-loop insulin systems [58]. Thus, the heterogene-

ity of devices adds complexity to synthesizing results across studies.

Methodological differences further contribute to discrepancies. Observational designs dominated the studies conducted in Gulf countries, potentially introducing biases related to data collection and analysis. This contrasts with the randomized controlled trials (RCTs) frequently employed in Western research, which provide more robust evidence through randomization and blinding. The reliance on observational designs in this review reflects the practical challenges of conducting RCTs in the fasting context but also limits the comparability of results with those derived from controlled experimental settings.

4.2. Implications for Practice and Future Research

This review highlights the transformative potential of advanced insulin delivery systems, especially in culturally specific contexts like Ramadan fasting. The findings strongly advocate for integrating AID and CSII systems into routine diabetes care, particularly for patients engaging in fasting. However, to maximize the impact of these technologies, it is crucial to provide tailored patient education and support. Such interventions can help address common challenges, including the behavioral and cultural barriers identified in this review.

Despite the promising findings, there remains an urgent need for large-scale, multicenter RCTs to validate the observed benefits and address existing gaps. Future research should prioritize longitudinal studies that assess the long-term impact of AID systems on diabetes-related complications, as suggested by Dovc *et al.* These studies would provide critical insights into the sustainability of short-term benefits, such as HbA1c reductions and improved time-in-range, while also evaluating risks like diabetic ketoacidosis and device malfunctions over extended periods.

Comparative analyses are another key research area. Future investigations should evaluate different AID algorithms and technologies to identify the most effective systems for specific populations. For instance, research should examine whether algorithmic advancements can further enhance outcomes in fasting and non-fasting contexts. Additionally, researchers must focus on cultural adaptations to ensure the broad applicability of advanced insulin systems. As highlighted by Alsairafi *et al.*, addressing cultural and behavioral barriers to device adoption, such as those related to clothing and physical activity, is essential for optimizing patient satisfaction and adherence.

5. Conclusion

This research provides a comprehensive analysis of the efficacy and safety of advanced insulin delivery systems, particularly automated insulin dosing (AID) and continuous subcutaneous insulin infusion (CSII), in managing diabetes during culturally specific contexts such as Ramadan fasting. The findings consistently demonstrate that these technologies outperform traditional methods like multiple daily injections (MDI) across key outcomes, including glycemic control, hypogly-

cemia prevention, fasting adaptation, and patient satisfaction. The evidence highlights significant reductions in HbA1c, improved time-in-range, and lower incidences of severe hypoglycemia among users of advanced systems.

The unique challenges posed by fasting-related glycemic variability further underscore the adaptability and safety of AID and CSII technologies. This review identifies the transformative potential of these systems, advocating their integration into routine diabetes care, particularly for patients in religious and cultural settings that influence dietary practices.

However, the research also reveals critical gaps that future investigations must address. The lack of large-scale, multicenter randomized controlled trials (RCTs), limited longitudinal data, and the need for culturally sensitive interventions remain significant barriers. Comparative analyses of different algorithms and real-world applications of these technologies will further enhance their efficacy and accessibility.

In conclusion, advanced insulin delivery systems represent a paradigm shift in diabetes management, offering innovative solutions to improve health outcomes, patient satisfaction, and quality of life. By addressing existing gaps and incorporating diverse patient needs, these technologies hold the promise of transforming diabetes care globally.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Bliss, M. (1982) The Discovery of Insulin. University of Chicago Press.

[2] Pickup, J. and Keen, H. (2002) Continuous Subcutaneous Insulin Infusion at 25 Years: Evidence Base for the Expanding Use of Insulin Pump Therapy in Type 1 Diabetes. *Diabetes Care*, **25**, 593-598. https://doi.org/10.2337/diacare.25.3.593

[3] JDRF CGM Study Group (2008) Continuous Glucose Monitoring and Intensive Treatment of Type 1 Diabetes. *New England Journal of Medicine*, **359**, 1464-1476.

[4] Kovatchev, B.P., Renard, E., Cobelli, C., Zisser, H.C., Anderson, S.M., Breton, M.D., *et al.* (2009) Multinational Study of Subcutaneous Model-Predictive Closed-Loop Control in Type 1 Diabetes Mellitus: Summary of the Results. *Journal of Diabetes Science and Technology*, **3**, 1054-1061.

[5] Kudva, Y.C., Carter, R.E., Cobelli, C., Basu, A. and Basu, R. (2014) Closed-Loop Artificial Pancreas Systems: Physiologic Input-To-Output Modeling. *Journal of Diabetes Science and Technology*, **8**, 308-320.

[6] Peters, A.L., Ahmann, A.J., Battelino, T., Evert, A., Hirsch, I.B., Murad, M.H., *et al.* (2016) Diabetes Technology—Continuous Subcutaneous Insulin Infusion Therapy and Continuous Glucose Monitoring in Adults: An Endocrine Society Clinical Practice Guideline. *The Journal of Clinical Endocrinology & Metabolism*, **101**, 3922-3937. https://doi.org/10.1210/jc.2016-2534

[7] Dovc, K. and Battelino, T. (2020) Closed-Loop Insulin Delivery Systems for Type 1 Diabetes. *Endocrinology and Metabolism Clinics of North America*, **49**, 139-151.

[8] Hovorka, R. (2011) Continuous Glucose Monitoring and Closed-Loop Systems. *Diabetic Medicine*, **28**, 1372-1382.

[9] Barnard, K.D., Wysocki, T., Allen, J.M., Elleri, D., Heinemann, L., Hoogma, R., *et al.* (2015) Closing the Loop in Adults, Children and Adolescents with Type 1 Diabetes. *Diabetes, Obesity and Metabolism*, **17**, 872-880.

[10] Lewis, D. and Leibrand, S. (2016) Real-world Use of Open Source Artificial Pancreas Systems. *Journal of Diabetes Science and Technology*, **10**, 1411-1411. https://doi.org/10.1177/1932296816665635

[11] Weitzman, E.R., Kaci, L. and Mandl, K.D. (2015) Sharing Medical Data for Health Research: The Early Personal Health Record Experience. *Journal of Medical Internet Research*, **17**, e5.

[12] Renard, E. (2005) Monitoring Glycemic Control: The Importance of Glucose Sensors. *Endocrinology and Metabolism Clinics of North America*, **34**, 49-57.

[13] DeVries, J.H. (2013) Glucose Variability: Where It Is Important and How to Measure It. *Diabetes*, **62**, 1405-1408. https://doi.org/10.2337/db12-1610

[14] Leelarathna, L., Choudhary, P., Wilmot, E.G. and Hovorka, R. (2016) How to Integrate New Diabetes Technologies into Clinical Practice: Challenges and Solutions. *Diabetes Management*, **6**, 263-271.

[15] Berget, C., Messer, L.H. and Forlenza, G.P. (2019) A Clinical Overview of Insulin Pump Therapy for the Management of Diabetes: Evidence, Policy, and Recommendations for Payers. *American Journal of Managed Care*, **25**, 86-90.

[16] Hovorka, R., Kumareswaran, K., Harris, J., Allen, J.M., Elleri, D., Xing, D., *et al.* (2011) Overnight Closed Loop Insulin Delivery (Artificial Pancreas) in Adults with Type 1 Diabetes: Crossover Randomised Controlled Studies. *BMJ*, **342**, d1855. https://doi.org/10.1136/bmj.d1855

[17] Al-Sofiani, M.E., Alharthi, S., Albunyan, S., Alzaman, N., Klonoff, D.C. and Alguwaihes, A. (2024) A Real-World Prospective Study of the Effectiveness and Safety of Automated Insulin Delivery Compared with Other Modalities of Type 1 Diabetes Treatment during Ramadan Intermittent Fasting. *Diabetes Care*, **47**, 683-691. https://doi.org/10.2337/dc23-1968

[18] Bruttomesso, D., Farret, A., Costa, S., Marescotti, M.C., Vettore, M., Avogaro, A., *et al.* (2009) Closed-Loop Artificial Pancreas Using Subcutaneous Glucose Sensing and Insulin Delivery and a Model Predictive Control Algorithm: Preliminary Studies in Padova and Montpellier. *Journal of Diabetes Science and Technology*, **3**, 1014-1021. https://doi.org/10.1177/193229680900300504

[19] Deeb, A., Al Qahtani, N., Akle, M., Singh, H., Assadi, R., Attia, S., *et al.* (2017) Attitude, Complications, Ability of Fasting and Glycemic Control in Fasting Ramadan by Children and Adolescents with Type 1 Diabetes Mellitus. *Diabetes Research and Clinical Practice*, **126**, 10-15. https://doi.org/10.1016/j.diabres.2017.01.015

[20] Alamoudi, R., Alsubaiee, M., Alqarni, A., Saleh, Y., Aljaser, S., Salam, A., *et al.* (2017)

Comparison of Insulin Pump Therapy and Multiple Daily Injections Insulin Regimen in Patients with Type 1 Diabetes during Ramadan Fasting. *Diabetes Technology & Therapeutics*, **19**, 349-354. https://doi.org/10.1089/dia.2016.0418

[21] Afandi, B., Kaplan, W., Al Hassani, N., Hadi, S. and Mohamed, A. (2017) Correlation between Pre-Ramadan Glycemic Control and Subsequent Glucose Fluctuation during Fasting in Adolescents with Type 1 Diabetes. *Journal of Endocrinological Investigation*, **40**, 741-744. https://doi.org/10.1007/s40618-017-0633-y

[22] Klonoff, D.C., Buckingham, B., Christiansen, J.S., Montori, V.M., Tamborlane, W.V., Vigersky, R.A., *et al.* (2011) Continuous Glucose Monitoring: An Endocrine Society Clinical Practice Guideline. *The Journal of Clinical Endocrinology & Metabolism*, **96**, 2968-2979.

[23] Thabit, H. and Hovorka, R. (2012) Closed-Loop Insulin Delivery in Type 1 Diabetes. *Endocrinology and Metabolism Clinics of North America*, **41**, 105-117. https://doi.org/10.1016/j.ecl.2011.12.003

[24] Deeb, A., Al Qahtani, N., Attia, S., Al Suwaidi, H. and Nagelkerke, N. (2016) Does Reducing Basal Insulin during Ramadan Fasting by Children and Adolescents with Type 1 Diabetes Decrease the Risk of Symptomatic Hypoglycemia? *Diabetes Technology & Therapeutics*, **18**, 539-542. https://doi.org/10.1089/dia.2016.0197

[25] Nevo-Shenker, M., Phillip, M., Nimri, R. and Shalitin, S. (2019) Type 1 Diabetes Mellitus Management in Young Children: Implementation of Current Technologies. *Pediatric Research*, **87**, 624-629. https://doi.org/10.1038/s41390-019-0665-4

[26] Wilson, L.M., Jacobs, P.G., Ramsey, K.L., Resalat, N., Reddy, R., Branigan, D., *et al.* (2020) Dual-Hormone Closed-Loop System Using a Liquid Stable Glucagon Formulation versus Insulin-Only Closed-Loop System Compared with a Predictive Low Glucose Suspend System: An Open-Label, Outpatient, Single-Center, Crossover, Randomized Controlled Trial. *Diabetes Care*, **43**, 2721-2729. https://doi.org/10.2337/dc19-2267

[27] Wilmot, E.G. and Danne, T. (2020) DIY Artificial Pancreas Systems: The Clinician Perspective. *The Lancet Diabetes & Endocrinology*, **8**, 183-185. https://doi.org/10.1016/s2213-8587(19)30416-4

[28] LeRoith, D. and Smith, D.O. (2005) Monitoring Glycemic Control: The Cornerstone of Diabetes Care. *Clinical Therapeutics*, **27**, 1489-1499. https://doi.org/10.1016/j.clinthera.2005.10.010

[29] Alsairafi, Z.K., Smith, F.J., Taylor, K.M.G., Alsaleh, F. and Alattar, A.T. (2018) A Qualitative Study Exploring Patients' Experiences Regarding Insulin Pump Use. *Saudi Pharmaceutical Journal*, **26**, 487-495. https://doi.org/10.1016/j.jsps.2018.02.010

[30] Almazrouei, R., Sharma, C., Afandi, B., Aldahmani, K.M., Aburawi, E.H., Beshyah, S.A., *et al.* (2022) Continuous Subcutaneous Insulin Infusion Is Associated with a Better Glycemic Control than Multiple Daily Insulin Injections without Difference in Diabetic Ketoacidosis and Hypoglycemia Admissions among Emiratis with Type 1 Diabetes. *PLOS ONE*, **17**, e0264545. https://doi.org/10.1371/journal.pone.0264545

[31] Alshahrani, A. (2024) Abstract #1851113 Comparative Study of Glycemic Control and Treatment Satisfaction for Patients with Type 1 Diabetes on Sensor-Augmented Insulin Pump, Insulin Pump, and Multiple Daily Insulin Injection: Cross-Sectional Study. *Endocrine Practice*, **30**, S1. https://doi.org/10.1016/j.eprac.2024.09.019

[32] Khalil, A.B., Beshyah, S.A., Abu Awad, S.M., Benbarka, M.M., Haddad, M., Al-Hassan, D., *et al.* (2012) Ramadan Fasting in Diabetes Patients on Insulin Pump Ther-

apy Augmented by Continuous Glucose Monitoring: An Observational Real-Life Study. *Diabetes Technology & Therapeutics*, **14**, 813-818. https://doi.org/10.1089/dia.2012.0061

[33] Haidar, A., Legault, L., Dallaire, M., Alkhateeb, A., Coriati, A., Messier, V., *et al.* (2013) Glucose-responsive Insulin and Glucagon Delivery (Dual-Hormone Artificial Pancreas) in Adults with Type 1 Diabetes: A Randomized Crossover Controlled Trial. *Canadian Medical Association Journal*, **185**, 297-305. https://doi.org/10.1503/cmaj.121265

[34] Arabi, Y.M., Dabbagh, O.C., Tamim, H.M., Al-Shimemeri, A.A., Memish, Z.A., Haddad, S.H., *et al.* (2008) Intensive versus Conventional Insulin Therapy: A Randomized Controlled Trial in Medical and Surgical Critically Ill Patients. *Critical Care Medicine*, **36**, 3190-3197. https://doi.org/10.1097/ccm.0b013e31818f21aa

[35] Landau, Z., Raz, I., Wainstein, J., Bar-Dayan, Y. and Cahn, A. (2016) The Role of Insulin Pump Therapy for Type 2 Diabetes Mellitus. *Diabetes/Metabolism Research and Reviews*, **33**, e2822. https://doi.org/10.1002/dmrr.2822

[36] Roze, S., Smith-Palmer, J., Valentine, W.J., Cook, M., Jethwa, M., de Portu, S., *et al.* (2015) Long-Term Health Economic Benefits of Sensor-Augmented Pump Therapy vs Continuous Subcutaneous Insulin Infusion Alone in Type 1 Diabetes: A UK Perspective. *Journal of Medical Economics*, **19**, 236-242. https://doi.org/10.3111/13696998.2015.1113979

[37] Rodbard, D. (2017) Continuous Glucose Monitoring: A Review of Recent Studies Demonstrating Improved Glycemic Outcomes. *Diabetes Technology & Therapeutics*, **19**, S-25-S-37. https://doi.org/10.1089/dia.2017.0035

[38] Keyu, G., Jiaqi, L., Liyin, Z., Jianan, Y., Li, F., Zhiyi, D., *et al.* (2022) Comparing the Effectiveness of Continuous Subcutaneous Insulin Infusion with Multiple Daily Insulin Injection for Patients with Type 1 Diabetes Mellitus Evaluated by Retrospective Continuous Glucose Monitoring: A Real-World Data Analysis. *Frontiers in Public Health*, **10**, Article 990281. https://doi.org/10.3389/fpubh.2022.990281

[39] Köprülü, Ö., Tan, H., Erbaş, İ.M., Şimşek, F.Y., Uyar, N., Karataş, M.Ç., *et al.* (2025) Risk of Diabetes-Specific Eating Disorders in Children with Type 1 Diabetes Mellitus Using Continuous Subcutaneous Insulin Infusion: A CGM-Based Cross-Sectional Study. *Medicina*, **61**, Article 1585. https://doi.org/10.3390/medicina61091585

[40] Alarcón, P.P., Álvarez, E.D., Lambert Goitia, C., Rodríguez, M.M., Urbon, L., Maldonado, A., *et al.* (2025) Does Combining a Mobile Dose Calculation App with a Continuous Insulin Infusion System Improve Glycemic Control and Quality of Life Compared with a Hybrid System in Patients with Type 1 Diabetes? A Descriptive Open-Label Sequential Study. *Diabetes Technology & Therapeutics*, **27**, 849-857. https://doi.org/10.1177/15209156251363452

[41] Jalilova, A., Pilan, B.Ş., Demir, G., Özbaran, B., Balkı, H.G., Arslan, E., *et al.* (2024) The Psychosocial Outcomes of Advanced Hybrid Closed-Loop System in Children and Adolescents with Type 1 Diabetes. *European Journal of Pediatrics*, **183**, 3095-3103. https://doi.org/10.1007/s00431-024-05551-1

[42] Bassi, M., Spacco, G., Pezzotta, F., Di Jorgi, M., Siri, G., Pintabona, A., *et al.* (2025) Real-World Efficacy of MiniMed™780G Recommended Settings (Glycemic Target 100 mg/dL, Active Insulin Time 2 Hours) in Youth and Young Adults with Type 1 Diabetes. *Frontiers in Endocrinology*, **16**, Article 1670266. https://doi.org/10.3389/fendo.2025.1670266

[43] Bombaci, B., Calderone, M., Di Pisa, A., La Rocca, M., Torre, A., Lombardo, F., *et al.*

(2025) Impact of Automated Insulin Delivery Systems in Children and Adolescents with Type 1 Diabetes Previously Treated with Multiple Daily Injections: A Single-Center Real-World Study. *Medicina*, **61**, Article 1602. https://doi.org/10.3390/medicina61091602

[44] Wolf, R.M., Patel, D., Gera, S., Molano, G., Dolivera, T., Meighan, S., *et al.* (2025) Does the OP5 Automated Insulin Delivery System Close the Gap in Glycemic Control between White and Black Youth with Type 1 Diabetes? *Diabetes Technology & Therapeutics*, **27**, 469-478. https://doi.org/10.1089/dia.2024.0612

[45] Stahl-Pehe, A., Shokri-Mashhadi, N., Wirth, M., Schlesinger, S., Kuss, O., Holl, R.W., *et al.* (2025) Efficacy of Automated Insulin Delivery Systems in People with Type 1 Diabetes: A Systematic Review and Network Meta-Analysis of Outpatient Randomised Controlled Trials. *eClinicalMedicine*, **82**, Article ID: 103190. https://doi.org/10.1016/j.eclinm.2025.103190

[46] Wadwa, R.P., *et al.* (2023) Trial of Hybrid Closed Loop Control in Young Children with Type 1 Diabetes. *New England Journal of Medicine*, **388**, 991-1001.

[47] Pujante, P., García, A.V., Villa-Fernández, E., García-Villarino, M., González-Vidal, T., Díaz-Naya, L., *et al.* (2025) One-Year Evaluation of Automated Insulin Delivery Systems in Adults with Type 1 Diabetes. *Frontiers in Digital Health*, **7**, Article 1596188. https://doi.org/10.3389/fdgth.2025.1596188

[48] Lee, T. T. M., *et al.* (2023) Automated Insulin Delivery in Women with Pregnancy Complicated by Type 1 Diabetes. *New England Journal of Medicine*, **389**, 1566-1578.

[49] Beunen, K., Van Wilder, N., Ballaux, D., Vanhaverbeke, G., Taes, Y., Aers, X., *et al.* (2023) Closed-loop Insulin Delivery in Pregnant Women with Type 1 Diabetes (CRISTAL): A Multicentre Randomized Controlled Trial—Study Protocol. *BMC Pregnancy and Childbirth*, **23**, Article No. 180. https://doi.org/10.1186/s12884-023-05481-0

[50] Azahaf, S., Beunen, K., Van Wilder, N., Ballaux, D., Vanhaverbeke, G., Taes, Y., *et al.* (2025) Cost-effectiveness of Advanced Hybrid Closed Loop Therapy Compared to Standard Insulin Therapy for Type 1 Diabetes in Pregnancy: An Economic Evaluation of the CRISTAL Trial. *eClinicalMedicine*, **81**, Article ID: 103106. https://doi.org/10.1016/j.eclinm.2025.103106

[51] Doyle, F.J. and Kovatchev, B.P. (2025) Artificial Pancreas: The First 20 Years*. *Diabetes Technology & Therapeutics*, **27**, S1-S8. https://doi.org/10.1089/dia.2025.0134

[52] Wang, X., *et al.* (2025) Effectiveness and Safety of AI-Driven Closed-Loop Systems in Diabetes Management: A Systematic Review and Meta-Analysis. *Diabetology & Metabolic Syndrome*, **17**, Article No. 238.

[53] Kitagawa, H., Munekage, M., Seo, S. and Hanazaki, K. (2025) Artificial Pancreas: The Past and the Future. *Journal of Artificial Organs*. https://doi.org/10.1007/s10047-025-01510-1

[54] Kadiyala, N., Hovorka, R. and Boughton, C.K. (2024) Closed Loop Systems: Recent Advancements and Lived Experience. *Expert Review of Medical Devices*, **21**, 927-941.

[55] Goede, S.L., Snels, V.H., Berghuis, W.W.J.H., Bernards, J.P.C. and Wyder, U. (2024) A Novel Pulse-Modulated Closed-Loop Artificial Pancreas Based on Intravenous Administration of Insulin and Glucagon. *Scientific Reports*, **14**, Article No. 16659. https://doi.org/10.1038/s41598-024-77800-0

[56] Niu, Y. and Lam, S. K. (2025) Securing Automated Insulin Delivery Systems: A Review of Security Threats and Protective Strategies. arXiv: 2503.14006.

[57] Mameche, O., *et al.* (2025) Precise Insulin Delivery for Artificial Pancreas: A Reinforce-

ment Learning Optimized Adaptive Fuzzy Control Approach. arXiv: 2503.06701.

[58] De Carli, S., Licini, N., Previtali, D., Previdi, F. and Ferramosca, A. (2025) Integrating Biological-Informed Recurrent Neural Networks for Glucose-Insulin Dynamics Modeling. *IFAC-PapersOnLine*, **59**, 91-96. https://doi.org/10.1016/j.ifacol.2025.06.016