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Efficacy and Safety of Automated Insulin Delivery Systems in Children and Adolescents With Type 1 Diabetes: A Systematic Review of Randomized Controlled Trials

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Abstract

Automated insulin delivery (AID) systems integrate continuous glucose monitoring (CGM) with algorithm-driven insulin delivery and are increasingly used in children and adolescents with type 1 diabetes (T1D). However, the magnitude and consistency of glycemic benefit across pediatric age groups, together with the safety profile of these systems, warrant focused evaluation. We conducted a systematic review of randomized controlled trials evaluating AID systems in children and adolescents with T1D. PubMed/MEDLINE, Embase, Cochrane CENTRAL, and ClinicalTrials.gov were searched from inception through August 2026. Eligible studies compared AID with conventional insulin therapy or non-automated pump/CGM-based management and reported glycemic or safety outcomes. Risk of bias was assessed using the Cochrane Risk of Bias 2 tool. Findings were synthesized narratively without quantitative meta-analysis.

Of 2,363 records identified, 11 randomized controlled trials met the eligibility criteria. Trials evaluated multiple AID platforms in participants aged 2-18 years, with intervention durations ranging from 12 to 104 weeks. AID consistently improved time in range (TIR) 70-180 mg/dL. Individual trials reported TIR improvements ranging from approximately 7 to 12 percentage points. In one pediatric trial, TIR increased by 11 percentage points (95% CI, 7-14; $P < 0.001$), while another demonstrated an 8.7-percentage-point increase (95% CI, 7.4-9.9; $P < 0.001$) accompanied by a 0.4-percentage-point reduction in glycated hemoglobin. A six-month trial demonstrated a 6.7-percentage-point increase in TIR (95% CI, 2.7-10.8; $P = 0.002$), with a concurrent 1.9-percentage-point reduction in time below range. Improvements were particularly pronounced during nighttime in several studies. Hyperglycemic exposure generally decreased, whereas hypoglycemia did not consistently increase. Severe hypoglycemia and diabetic ketoacidosis were uncommon, although the relatively small trial populations limited assessment of rare adverse events. Two trials were judged to have low overall risk of bias, while nine had some concerns; none was judged to have high risk of bias.

AID systems consistently improve CGM-derived glycemic outcomes in children and adolescents with T1D, with the most reproducible benefit being increased TIR and reduced hyperglycemic exposure. Improvements in glycated hemoglobin were comparatively modest. Current randomized evidence does not demonstrate a consistent increase in hypoglycemia or diabetic ketoacidosis, although longer and larger studies are needed to characterize rare safety outcomes. AID should be regarded as an effective strategy for reducing glycemic burden rather than a fully autonomous treatment. Future research should emphasize long-term clinical and psychosocial outcomes, treatment burden, technology-related complications, and representation of diverse pediatric populations.

Categories: Pediatrics, Internal Medicine

Keywords: adolescents, automated insulin delivery, children, continuous glucose monitoring, glycemic control, randomized controlled trials, time in range, type 1 diabetes

Introduction And Background

Type 1 diabetes (T1D) is one of the most common chronic diseases of childhood, and its global incidence in youth continues to rise: modeling estimates put the worldwide T1D population at over 8.4 million in 2021, with children and adolescents accounting for a substantial share of new diagnoses each year [1]. A separate global simulation-based analysis focused specifically on the pediatric and adolescent age range (0-19 years) similarly projects continued increases in incidence through 2050 across most world regions [2]. Children and adolescents living with this disease face a lifelong burden of glucose self-management, and intensive insulin therapy, whether delivered by multiple daily injections or continuous subcutaneous insulin infusion, remains the cornerstone of care. Yet glycemic control in this population continues to fall short of recommended targets for a substantial proportion of youth, in part because insulin dosing must be adjusted constantly against unpredictable variables such as growth, activity, illness, and the psychosocial demands of managing a chronic disease during childhood and adolescence.

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Continuous glucose monitoring (CGM) and insulin-pump technology have progressively reduced some of the practical burden of diabetes self-management while improving glucose exposure and limiting hypoglycemia. Automated insulin delivery (AID) systems integrate these technologies with a control algorithm that modifies insulin delivery in response to sensor glucose measurements. Depending on the system, automation may adjust basal insulin alone or also deliver correction doses, while meal-related bolusing generally still requires user input. Terms such as hybrid closed-loop and artificial pancreas are used for related technologies. The 2024 International Society for Pediatric and Adolescent Diabetes (ISPAD) consensus guidance specifically addresses insulin-delivery technologies, including AID, in children and adolescents with diabetes [3].

As more youth with T1D adopt AID systems and as national health systems weigh decisions about funding their coverage, the evidence base has grown accordingly, and clinical practice guidelines have begun to draw on it, generally concluding that there is strong evidence for AID systems' efficacy in improving glucose management [4]. However, the systematic reviews underlying these guideline recommendations carry several methodological limitations that constrain how confidently their conclusions translate into everyday pediatric practice. Some reviews pooled outcomes from children and adults together, as analyses restricted to pediatric participants alone were often not feasible given the smaller number of dedicated pediatric trials [5], while others restricted their scope to outpatient trial designs specifically, leaving supervised and inpatient evidence outside their synthesis [6]. In addition, even reviews restricted to pediatric-only populations have generally captured a wide age band without further stratifying findings by developmental stage [7,8].

This last gap is particularly consequential. Very young children (younger than seven years) differ from older youth in insulin sensitivity, day-to-day variability in insulin requirements, and the practical realities of caregiver-mediated rather than self-directed diabetes management. Until recently, this age group had not been systematically evaluated as a distinct population; this gap is only beginning to be addressed as pivotal trials in preschool-aged children have accumulated [9-11], and a dedicated synthesis of this age group has been published [12]. At the same time, regulatory approvals for commercial AID systems have progressively expanded to younger age groups, including children as young as two years, creating a growing mismatch between device availability and the maturity of the pediatric-specific evidence base guiding their use.

Taken together, these considerations support an updated systematic review focused exclusively on randomized evidence in children and adolescents with T1D. Although recent systematic reviews and meta-analyses have examined pediatric AID, differences in eligibility criteria, age ranges, trial settings, intervention duration, and outcomes assessed may lead to different clinical interpretations. The present review therefore focuses specifically on randomized controlled trials (RCTs) across the pediatric age spectrum and provides a structured narrative synthesis of glycemic efficacy, hypoglycemia, hyperglycemia, severe adverse events, treatment burden, and patient-reported outcomes across different AID platforms and durations of use. Unlike quantitative meta-analyses, the present review does not statistically pool treatment effects; instead, it examines the consistency, magnitude, and clinical context of findings across individual randomized trials.

The objective of this systematic review was to evaluate the efficacy and safety of AID systems in children and adolescents with T1D. The review question was structured according to the Population, Intervention, Comparator, and Outcomes (PICO) framework: Population, children and adolescents with T1D; Intervention, AID systems; Comparator, conventional insulin therapy or non-automated pump/CGM-based management; and Outcomes, including time in range (TIR), HbA1c, time below range (TBR), time above range (TAR), hypoglycemia, hyperglycemia, severe hypoglycemia, diabetic ketoacidosis (DKA), adverse events, and patient-reported outcomes.

Review

Methodology

Study Design and Reporting

This systematic review was conducted to synthesize the available evidence on the efficacy, glycemic outcomes, and safety of AID systems in children and adolescents with T1D. The review was structured according to the PICO framework and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. PRISMA was used as a reporting framework to ensure transparent and reproducible reporting of the literature search, study selection, data extraction, and synthesis process; no meta-analysis was performed.

The protocol was not registered in International Prospective Register of Systematic Reviews (PROSPERO) or another public registry, and this is acknowledged as a limitation of the review. As the review analyzed only previously published, de-identified aggregate data, ethical approval and informed consent were not required.

Search Strategy

A comprehensive search of PubMed/MEDLINE, the Cochrane Central Register of Controlled Trials (CENTRAL), Embase, and ClinicalTrials.gov was performed from inception through August 2026, with no restrictions based on country of publication. The search strategy was developed using database-specific controlled vocabulary and free-text terms related to AID, T1D, children and adolescents, and relevant glycemic and safety outcomes. Search terms included concepts related to the intervention (e.g., “automated insulin delivery”, “closed-loop”, “artificial pancreas”, “hybrid closed-loop”, and “artificial beta cell”), the population (e.g., “type 1 diabetes”, “children”, “adolescents”, “pediatric”, and “youth”), and outcomes of interest (e.g., “time in range”, “glycated hemoglobin”, “hypoglycemia”, and “diabetic ketoacidosis”). Boolean operators (AND/OR) were used to combine the search concepts, with appropriate adaptations made according to the requirements of each database. The search was conducted from database inception to August 2026. Only original RCTs were considered for the primary evidence synthesis. Editorials, conference abstracts, clinical practice guidelines, narrative reviews, and other systematic reviews were excluded from primary data extraction; however, relevant systematic reviews and other secondary sources were hand-searched for additional eligible trials. The review followed a PICO framework: P, children and adolescents with T1D; I, AID system use; C, conventional insulin therapy or non-automated sensor-augmented pump therapy; and O, glycemic and safety outcomes, including TIR, glycated hemoglobin, hypoglycemia, hyperglycemia, severe hypoglycemia, and diabetic ketoacidosis. The search process, including the database-specific search terms and final search date, was documented to enhance transparency and reproducibility.

Eligibility Criteria

Studies were eligible if they evaluated children or adolescents with T1D who received an AID intervention and included a comparator receiving conventional insulin management. AID was defined as an insulin-delivery system integrating CGM with an automated control algorithm capable of adjusting insulin delivery in response to glucose measurements. Eligible comparator therapies included multiple daily injections, conventional insulin pump therapy, and sensor-augmented pump therapy without AID. RCTs, including parallel-group and randomized crossover designs, were considered eligible. Studies were required to report at least one relevant glycemic, metabolic, or safety outcome. Observational studies, case reports, case series, nonrandomized studies, and uncontrolled single-arm studies were excluded from the primary evidence synthesis.

Study Selection

After removal of duplicate records, titles and abstracts were screened against the predefined eligibility criteria, followed by full-text assessment of potentially eligible reports. The number of records excluded at the title/abstract and full-text stages was documented, and the reasons for exclusion at the full-text stage were recorded. The complete study-selection process is presented in the PRISMA flow diagram (Figure 1). Following full-text assessment, 11 RCTs met the predefined eligibility criteria and were included in the primary evidence synthesis.

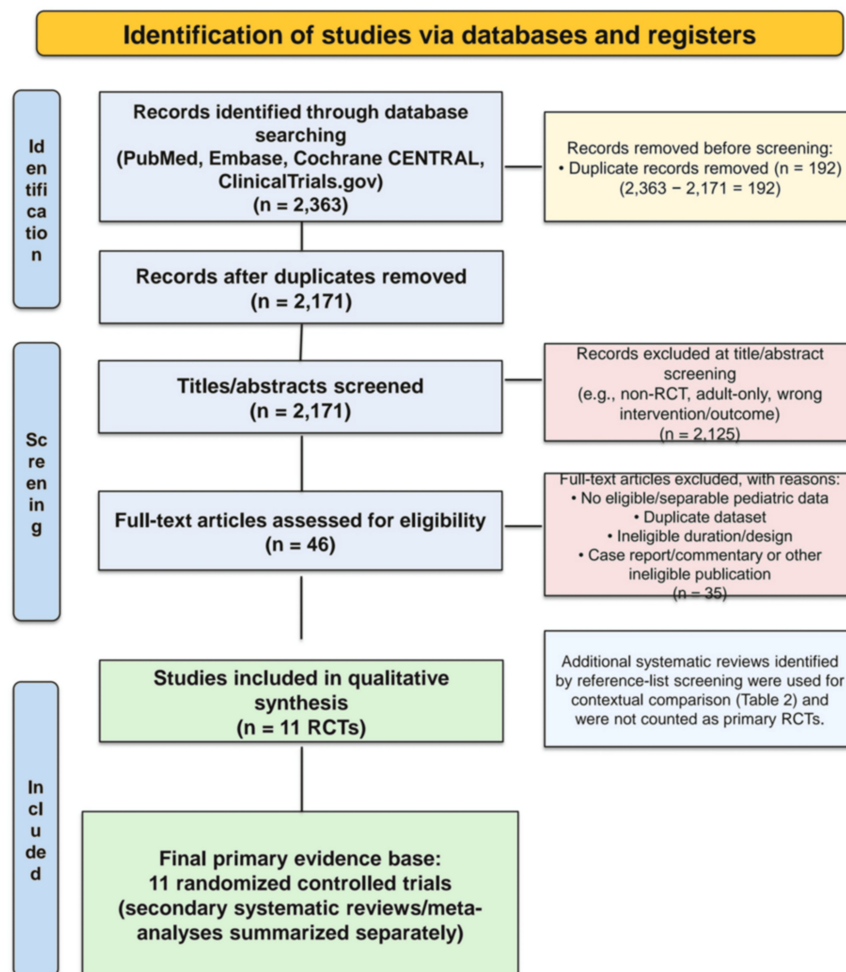


FIGURE 1: PRISMA 2020 flow diagram

PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses

Data Extraction

Data were extracted using a prespecified standardized extraction form. Information was collected on study characteristics, country and setting, sample size, participant characteristics, trial design, intervention and comparator details, AID platform, glucose-monitoring and insulin-delivery technologies, intervention duration, and prespecified efficacy and safety outcomes. Efficacy outcomes included glycated hemoglobin (HbA1c), TIR, TBR, TAR, and daytime and nighttime glucose measures. Safety and other clinical outcomes included severe hypoglycemia, diabetic ketoacidosis, serious adverse events, treatment discontinuation, and patient-reported outcomes, when available. Multiple reports from the same trial were considered together to avoid double-counting participants.

Outcome Assessment

The principal outcomes of interest were glycemic control and CGM-derived glucose metrics, particularly HbA1c and TIR, defined as the percentage of time spent within 70–180 mg/dL (3.9–10.0 mmol/L). Secondary outcomes included TBR, TAR, nighttime and daytime glucose metrics, severe hypoglycemia, DKA, serious adverse events, and treatment-related or patient-reported outcomes. Outcomes were extracted as reported in the original studies, and differences in outcome definitions or assessment periods were considered during interpretation.

Risk-of-Bias Assessment

Risk of bias was assessed across the five RoB 2 domains: randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported results. Each study was categorized as having low risk of bias, some concerns, or high risk of bias according to the predefined signaling questions and domain-level judgments. Because participant and clinician blinding is generally impractical for device-based AID interventions, the interpretation of this domain was considered in relation to the objectivity of the outcomes assessed. Any disagreements during study selection, data extraction, or risk-of-bias assessment were resolved through discussion and consensus; when consensus could not be reached, a third reviewer was consulted.

Evidence Synthesis

Because this study was designed as a systematic review without quantitative meta-analysis, findings were synthesized narratively. The results were organized according to study characteristics, AID technology, comparator therapy, intervention duration, participant age, and reported clinical outcomes. Individual study findings were compared with respect to changes in HbA1c, TIR, TBR, TAR, hypoglycemia, hyperglycemia, safety outcomes, and patient-reported outcomes. Particular attention was given to the consistency of findings across different AID platforms and pediatric age groups.

Where studies differed substantially in design, intervention, duration, outcome definitions, or reporting, findings were described separately rather than mathematically combined. The direction, magnitude, and clinical relevance of reported effects were considered when interpreting the overall evidence.

Reporting of Results

The characteristics of the included RCTs are presented in Table 1, and the principal findings from previously published systematic reviews and meta-analyses are summarized separately in Table 2. The study selection process is shown in Figure 1, while the study-level RoB 2 judgments are displayed in Figure 2.

Study	Country/Setting	Sample Size (n) and Age (years)	AID System/Device	Comparator	Duration	Key Glycemic Findings
Tauschmann et al., 2018 [13]	UK, multicenter	n=86; ≥6 y	MiniMed 670G/FlorenceM	SAP	12 wk	Improved TIR compared with SAP
Breton et al., 2020 [14]	USA, multicenter	n=101; 6–12 y	t:slim X2/Control-IQ	SAP	16 wk	Increased TIR and improved glycemic control
Abraham et al., 2021 [15]	Australia, multicenter	n=110; 12–18 y	MiniMed 670G/SmartGuard	CSII or MDI	26 wk	Improved TIR with AID
Isganaitis et al., 2021 [16]	USA, multicenter	n=63; 14–24 y	t:slim X2/Control-IQ	SAP	24 wk	Improved TIR and HbA1c
Burnside et al., 2022 [17]	New Zealand	n=48; 7–15 y	DANA-I/OpenAPS	SAP	24 wk	Increased TIR with automated insulin delivery
Reiss et al., 2022 [18]	USA	n=42; 14–17 y	MiniMed 670G	MDI or SAP	24 wk	Evaluated glycemic and neurocognitive/gray-matter outcomes
Ware et al., 2022 [19]	Multicenter	n=133; 6–18 y	Dana Diabecare RS/FlorenceM or CamAPS	CSII	24 wk	Improved HbA1c and glycemic control
Boughton et al., 2022 [20]	UK, multicenter	n=97; 10–17 y	t:slim X2/CamAPS	MDI	104 wk	Long-term AID use associated with improved glycemic management
Messer et al., 2022 [21]	USA, multicenter	n=165; 6–17 y	iLet/Bionic Pancreas	Standard care/CGM	13 wk	Improved HbA1c and TIR
McVean et al., 2023 [22]	USA, multicenter	n=108; 7–17 y	Control-IQ or SmartGuard	CGM-based standard care	52 wk	Sustained improvement in glycemic control
Garg et al., 2023 [23]	USA, multicenter	n=302; adults:18–80 y and children: 2–17y	MiniMed 670G/SmartGuard	SAP	24 wk	Improved HbA1c and glycemic control

TABLE 1: Characteristics and glycemic outcomes of the 11 RCTs evaluating AID in children and adolescents with type 1 diabetes

Note: the characteristics of the mentioned RCTs include sample size, age, device, algorithm, comparator, duration, and key glycemic findings.

SAP, sensor-augmented pump therapy; CSII, continuous subcutaneous insulin infusion; MDI, multiple daily injection; TIR, time in range; AID, automated insulin delivery; HbA1c, glycated hemoglobin; CGM, continuous glucose monitoring; RCT, randomized controlled trial

Review	Population	Studies/Participants	Main Scope	Principal Findings
Michou et al., 2023 [7]	Children/adolescents <21 y with T1D	26 RCTs; 915 participants	Efficacy of AID across pediatric age groups	Significant improvement in TIR, hypoglycemia-related outcomes, and HbA1c with AID versus control
Zeng et al., 2023 [6]	Children/adolescents with T1D in outpatient settings	25 RCTs; 1,345 participants	CGM-derived outcomes	TIR +11.38 percentage points; TBR −0.59 pp; TAR −12.19 pp
de Visser et al., 2025 [8]	Youth with T1D	11 RCTs; 901 participants for HbA1c; 786 for TIR	Prolonged outpatient AID	HbA1c −0.41%; TIR +11.5 pp; nighttime TIR +19.7 pp
Lin et al., 2026 [24]	Children <7 y with T1D	4 RCTs; 292 participants	Very young children	TIR +9.29 pp; HbA1c −0.39%; no significant difference in severe hypoglycemia or DKA
Oktavian et al., 2026 [12]	Young children with T1D	30 studies; 1,155 participants	RCT and observational/real-world evidence	TIR improved by approximately 9.88 percentage points across diverse AID platforms

TABLE 2: Summary of findings reported in previously published systematic reviews and meta-analyses

The table summarizes findings reported in previously published systematic reviews and meta-analyses and does not represent a quantitative synthesis performed in the present review

T1D, type 1 diabetes; RCTs, randomized controlled trials; AID, automated insulin delivery; TIR, time in range; HbA1c, glycated hemoglobin; CGM, continuous glucose monitoring; TBR, time below range; TAR, time above range; DKA, diabetic ketoacidosis; pp, percentage points; y, years



FIGURE 2: Traffic-light plot of risk of bias across the included randomized controlled trials using the Cochrane RoB 2 Tool

D1, randomization process; D2, deviations from intended interventions; D3, missing outcome data; D4, measurement of the outcome; D5, selection of the reported result

Results

Study Selection

The search yielded 2,363 records. After removal of 192 duplicate records, 2,171 unique records underwent title and abstract screening. Of these, 2,125 records were excluded at the screening stage, leaving 46 reports for full-text assessment. Thirty-five full-text reports were subsequently excluded because they did not meet the predefined eligibility criteria related to population, intervention, comparator, study design, or outcomes. Consequently, 11 RCTs were included in the final primary synthesis. The 11 eligible RCTs, published between 2018 and 2023, constituted the primary evidence base of this review and included children from early childhood through late adolescence. Findings from previously published systematic reviews and meta-analyses, non-randomized studies, single-arm studies, and extension studies were considered separately as contextual evidence and were not included in the primary study count or synthesis. Both parallel-group and randomized crossover designs were represented among the included trials. The evaluated technologies included FlorenceM/CamAPS, Medtronic SmartGuard, Tandem Control-IQ, OpenAPS, and the iLet bionic pancreas, while comparator approaches included sensor-augmented pump therapy, conventional pump therapy, multiple daily injections, and standard diabetes care. Intervention durations ranged from 12 to 104 weeks, providing evidence from both shorter-term trials and studies with longer follow-up.

Characteristics of Included Randomized Controlled Trials

The 11 included RCTs were published between 2018 and 2023 and evaluated AID systems in children and adolescents with T1D. The studies represented a broad pediatric age range, from early childhood to late adolescence, and included both parallel-group and randomized crossover designs.

The evaluated technologies included FlorenceM/CamAPS, Medtronic SmartGuard, Tandem Control-IQ, OpenAPS, and the iLet bionic pancreas. Comparator interventions included sensor-augmented pump therapy, conventional insulin pump therapy, multiple daily injections, and other standard insulin-management strategies. Intervention duration ranged from 12 weeks to 104 weeks, thereby providing evidence from both relatively short-term and prolonged outpatient AID use. These characteristics are summarized in Table 1 [13-23].

Impact of AID Systems on Time in Range and Glycated Hemoglobin

Across individual randomized trials, AID consistently improved TIR compared with control therapy. Breton et al. reported an adjusted TIR difference of 11 percentage points (95% CI, 7-14; $P < 0.001$) in children aged 6-13 years, equivalent to approximately 2.6 additional hours/day in range [14]. Ware et al. reported an 8.7-percentage-point increase in TIR (95% CI, 7.4-9.9; $P < 0.001$) in very young children, accompanied by a 0.4-percentage-point reduction in HbA1c (95% CI, -0.5 to -0.3; $P < 0.001$) [19]. In the six-month randomized trial by Abraham et al., TIR improved by 6.7 percentage points (95% CI, 2.7-10.8; $P = 0.002$), while TBR decreased by 1.9 percentage points (95% CI, -2.5 to -1.3) [15]. In the Cambridge hybrid closed-loop trial, HbA1c was 0.32 percentage points lower with AID than control at 6 months (95% CI, -0.59 to -0.04; $P = 0.023$) [19]. In children aged two to six years, TIR improved by 12.4 percentage points (95% CI, 9.5-15.3; $P < 0.001$) with hybrid closed-loop therapy. Overall, the individual trials therefore showed a relatively consistent improvement in TIR, generally in the range of approximately 7-12 percentage points, with smaller but significant reductions in HbA1c in several studies.

Effects on Time Above Range and Hyperglycemia

Across individual trials, improvement in TIR was accompanied by reductions in hyperglycemic exposure, although the magnitude varied by age and AID platform. In the 16-week pediatric trial by Breton et al., TIR increased by 11 percentage points (95% CI, 7-14; $P < 0.001$), with mean nighttime TIR reaching 80% with closed-loop therapy versus 54% with sensor-augmented pump therapy, compared with a smaller daytime difference of 63% versus 56% [14]. In adolescents and young adults in the iDCL trial, Isganaitis et al. reported a 12-percentage-point reduction in time >180 mg/dL (approximately 2.9 hours/day; $P < 0.001$) with Control-IQ, corresponding closely to the 13-percentage-point improvement in TIR; time <70 mg/dL simultaneously decreased by 0.7 percentage points (95% CI, -1.0 to -0.2; $P = 0.002$) [16]. In the six-month Australian pediatric trial, Abraham et al. observed a reduction in time >180 mg/dL from 41.8% to 34.4% with hybrid closed-loop therapy compared with 39.4% to 37.9% in controls; however, the between-group difference of -4.3 percentage points (95% CI, -8.8 to 0.2; $P = 0.06$) did not reach statistical significance [15]. In contrast, the iLet bionic-pancreas trial in youth aged 6-17 years demonstrated significant improvements in both time >180 mg/dL and time >250 mg/dL ($P < 0.001$ for both), together with a 10-percentage-point increase in TIR, equivalent to approximately 2.4 additional hours/day [21]. Taken together, these trials show a broadly consistent improvement in TIR, while the change in HbA1c is generally smaller.

Effects on Time Below Range and Hypoglycemia

Importantly, the increase in TIR was generally achieved without a corresponding increase in CGM-defined

hypoglycemia. In Abraham et al.'s study, time <70 mg/dL decreased by 1.9 percentage points (95% CI, -2.5 to -1.3; $P<0.001$), while more severe thresholds also improved: time <54 mg/dL decreased by 0.5 percentage points (95% CI, -0.7 to -0.3; $P<0.001$) [15]. No episodes of severe hypoglycemia occurred in either group. In the Control-IQ adolescent/young-adult analysis, time <70 mg/dL decreased by 0.7 percentage points (95% CI, -1.0 to -0.2; $P=0.002$) despite a 13-percentage-point improvement in TIR. Ware et al. similarly found no significant increase in time below 70 mg/dL in very young children, with median hypoglycemia remaining low and no significant between-group difference ($P=0.74$) [9]. In the iLet youth trial, time <54 mg/dL was low at baseline (median 0.2%) and did not differ significantly between groups ($P=0.24$); severe hypoglycemia occurred in 3 (2.7%) of 112 participants receiving the bionic pancreas and 1 (1.9%) of 53 participants receiving standard care [21]. Collectively, these findings indicate that the increase in TIR was not generally accompanied by increased exposure to biochemical hypoglycemia, although the relatively low event rates limit conclusions regarding rare severe hypoglycemic events.

Daytime and Nighttime Glycemic Outcomes

The improvement in glycemic control was particularly pronounced during nighttime periods in several studies. In the pediatric trial by Breton et al., mean nighttime TIR was 80% with closed-loop therapy versus 54% with sensor-augmented pump therapy, while daytime TIR was 63% versus 56%, respectively, indicating a substantially larger absolute improvement overnight [14]. A similar pattern was observed in the adolescent/young-adult iDCL analysis, in which the adjusted improvement in TIR was 19 percentage points overnight (95% CI, 13-24; $P<0.0001$) compared with 11 percentage points during daytime (95% CI, 7-14; $P<0.0001$) [16]. In the open-source AID trial, the pediatric subgroup also showed greater TIR at night (76.8%) than during daytime (64.3%) with AID; corresponding control values were 57.2% and 50.9%, respectively [17]. The same study reported only 1.2% of overnight readings below 70 mg/dL in the AID group compared with 3.1% in controls [17]. In the very-young-child trial, improvement in TIR was observed during both daytime and nighttime, with the overall treatment effect corresponding to 12.4 percentage points (95% CI, 9.5-15.3; $P<0.001$) or approximately 3 additional hours/day in range [10]. These findings suggest that the nocturnal component of AID may contribute disproportionately to overall improvement in glucose exposure, although the magnitude of this effect differs between algorithms and populations.

Effects on Glycemic Variability

AID also affected measures of glucose variability, although these outcomes were less consistently reported than TIR and HbA1c. In the six-month Australian trial, the coefficient of variation was 5.7 percentage points lower with hybrid closed-loop therapy (95% CI, -10.2 to -0.9; $P=0.02$), while glucose standard deviation decreased by 4.9 mg/dL (95% CI, -9.2 to -0.6; $P=0.03$). In the iLet youth trial, analyses of standard deviation of CGM glucose also favored the bionic pancreas ($P<0.001$), alongside reductions in mean glucose and hyperglycemic exposure. In the Control-IQ adolescent/young-adult analysis, the improvement in TIR was primarily attributable to reduced hyperglycemia rather than increased glucose variability, with the intervention producing a 12-percentage-point reduction in time >180 mg/dL ($P<0.001$) while also reducing time <70 mg/dL by 0.7 percentage points (95% CI, -1.0 to -0.2; $P=0.002$). These results suggest that AID may improve the distribution and stability of glucose values in addition to increasing TIR, although heterogeneity in the variability metrics reported across trials limits direct comparison.

Safety Outcomes: Severe Hypoglycemia and Diabetic Ketoacidosis

Safety outcomes were generally reassuring, but rare events remained difficult to compare because of the relatively small sample sizes of individual pediatric trials. In the 6-month Australian RCT, no severe hypoglycemia or DKA occurred in either treatment group. Similarly, in the 24-week open-source AID trial, no severe hypoglycemia or DKA occurred in either group, although two participants in the AID group discontinued because of connectivity problems. In the iLet youth trial, severe hypoglycemia occurred in 3 (2.7%) of 112 participants receiving the bionic pancreas and 1 (1.9%) of 53 receiving standard care; no significant increase in CGM-defined hypoglycemia was observed. In contrast, the 24-month CLOuD trial in newly diagnosed adolescents reported five severe hypoglycemia cases in three participants in the closed-loop group versus one case in the control group, and one DKA event occurred in the closed-loop group. Importantly, the CLOuD trial was primarily designed to evaluate preservation of C-peptide rather than safety, and its population comprised newly diagnosed adolescents; therefore, these events should not be interpreted as representative of all established-T1D AID populations. Overall, the available trials do not demonstrate a consistent increase in severe hypoglycemia or DKA, but their limited event numbers preclude precise estimation of rare-event risk.

Patient-Reported Outcomes and Treatment Burden

Patient-reported outcomes were evaluated less consistently than CGM metrics. In the six-month Australian RCT, diabetes-specific quality of life improved by 4.4 points (95% CI, 0.4-8.4; $P=0.03$) with hybrid closed-loop therapy, whereas diabetes distress did not differ significantly between groups (-4.5 points; 95% CI, -10.6 to 1.6; $P=0.14$). Treatment satisfaction also differed between groups, with the reported difference among children being -3.3 points (95% CI, -6.0 to -0.6; $P=0.02$) and among adults being -5.2 points (95% CI,

−9.2 to −1.2; $P=0.01$) on the reported DTSQ measure. In the open-source AID trial, however, two participants withdrew because of connectivity problems, demonstrating that technical requirements can remain relevant even when glycemic efficacy is maintained. In the current pediatric evidence base, relatively few trials reported standardized measures of quality of life, diabetes distress, fear of hypoglycemia, or technology-related burden; consequently, the evidence is considerably less developed for psychosocial outcomes than for CGM-derived glycemic outcomes.

Evidence Across Different AID Platforms

The included trials evaluated technologically heterogeneous AID approaches, and the observed glycemic effects were broadly consistent across several platforms. Control-IQ produced a 13-percentage-point improvement in TIR (95% CI, 9–16; $P<0.001$) in adolescents and young adults, with a concurrent 12-percentage-point reduction in time >180 mg/dL ($P<0.001$). The Cambridge/CamAPS-based system increased TIR by 8.7 percentage points (95% CI, 7.4–9.9; $P<0.001$) in very young children, without increasing hypoglycemia. Open-source AID increased TIR by 12.6 percentage points (95% CI, 5.7–19.5) among children aged 7–15 years, corresponding to approximately 3 additional hours/day in range. The iLet bionic pancreas increased TIR by approximately 10 percentage points, reduced HbA1c by 0.5 percentage points (95% CI, −0.7 to −0.2; $P<0.001$), and improved hyperglycemic measures without increasing CGM-defined hypoglycemia. Although these findings demonstrate efficacy across different technological approaches, the trials were not head-to-head comparisons of all platforms; therefore, the results should be interpreted as evidence of benefit across AID technologies rather than evidence of superiority of one system over another.

Evidence From Existing Systematic Reviews and Meta-analyses

The findings from individual trials are broadly consistent with previously published systematic reviews and meta-analyses. Zeng et al. synthesized 25 outpatient studies involving 1,345 participants and reported an increase in TIR of 11.38 percentage points (95% CI, 9.01–13.76), together with reductions in time below and above range [6]. de Visser et al. subsequently restricted their evidence synthesis to pediatric RCTs and reported a pooled TIR improvement of 11.5 percentage points (95% CI, 9.3–13.7) and a pooled HbA1c reduction of 0.41 percentage points (95% CI, −0.58 to −0.25) [8]. These published pooled estimates are concordant with the direction and approximate magnitude of the individual-study effects identified in the present review. However, they are reported here only as secondary evidence from existing reviews and were not recalculated or pooled in the present systematic review.

Importantly, de Visser et al. also reported a larger improvement in nighttime TIR (19.7 percentage points; 95% CI, 17.0–22.4) than daytime TIR (8.5 percentage points; 95% CI, 5.9–11.1), consistent with the marked overnight effects observed in individual Control-IQ and other closed-loop trials [8]. For very young children, Lin et al. reported data from four RCTs involving 292 participants younger than seven years and found a 9.29-percentage-point improvement in TIR and a 0.39% reduction in HbA1c with AID [24]. Importantly, no significant differences were observed in severe hypoglycemia or DKA in that analysis. The convergence between individual RCT findings and previous evidence syntheses strengthens the consistency of the observed effect, while differences between studies in age, baseline HbA1c, comparator therapy, device algorithm, and automation time remain important sources of clinical heterogeneity.

Age-Related Pattern of Evidence

The included randomized evidence covered a broad pediatric age range, from 2 to 18 years, but the distribution of evidence was not uniform across developmental stages. Among the 11 RCTs, several trials enrolled predominantly school-aged children and adolescents, including Breton et al. (6–12 years; 16 weeks) [14], Abraham et al. (12–18 years; 26 weeks) [15], Burnside et al. (7–15 years; 24 weeks) [17], Reiss et al. (14–17 years; 24 weeks) [18], Ware et al. (6–18 years; 24 weeks) [19], and Messer et al. (6–17 years; 13 weeks) [21].

Evidence in younger children has also become increasingly represented. Ware et al. evaluated children as young as six years in their multicenter trial [19], while Garg et al. included children aged 2–17 years in a 24-week SmartGuard study [23]. In addition, evidence outside the 11-RCT set has specifically evaluated preschool-aged children. In a 13-week single-arm Omnipod 5 study of 80 children aged 2.0–5.9 years [11], TIR increased by 10.9 percentage points, equivalent to approximately 2.6 additional hours/day, while HbA1c decreased by 0.55 percentage points ($P<0.0001$) and time below 70 mg/dL decreased by 0.27 percentage points ($P=0.0204$); no severe hypoglycemia or DKA occurred.

Randomized evidence in the same preschool age range is provided by the PEDAP trial, which enrolled children aged 2 to <6 years for 13 weeks and compared closed-loop therapy with standard care [10]. Longer-term follow-up of the Omnipod 5 preschool cohort further showed that the glycemic improvement observed during the 13-week pivotal phase was maintained during extended use: among 80 children, median total AID exposure was 18.2 months, with TIR increasing from 57.2% during standard therapy to 68.1% during the pivotal phase and remaining 67.2% during the extension phase.

Duration of AID Use

The duration of the randomized trials varied substantially, from 12 weeks to 104 weeks. The 11 trials included in the recent pediatric RCT evidence base had intervention durations of 12 weeks [13], 13 weeks [21], 16 weeks [14], 24 weeks [16-19,23], 26 weeks [15], 52 weeks [22], and 104 weeks [20].

Importantly, measurable glycemic benefit was evident even during relatively short interventions. The 12-week Tauschmann trial and 13-week Messer trial demonstrated improvement in CGM-derived outcomes [13,14], whereas the 16-week Breton trial reported an approximately 11-percentage-point improvement in TIR (95% CI, 7-14; $P < 0.001$) [14]. Longer studies also demonstrated sustained effects. The 24-week Ware trial and 26-week Abraham trial reported significant improvements in glycemic outcomes [15,19], while the 52-week McVean study extended the observation period to approximately one year [22].

The longest randomized exposure was provided by Boughton et al., with 104 weeks of CamAPS-based closed-loop therapy in children and adolescents with newly diagnosed T1D [20]. This study primarily evaluated C-peptide preservation rather than glycemic control, and therefore its long duration should not be interpreted as evidence that all glycemic outcomes require two years to improve. Rather, it provides evidence regarding the feasibility of prolonged closed-loop exposure and long-term clinical follow-up.

The duration subgroup analysis reported by de Visser et al. provides a useful comparison across trials [8]. For TIR, the pooled improvement was 11.99 percentage points (95% CI, 8.70-15.29) in trials lasting <6 months and 11.37 percentage points (95% CI, 8.33-14.41) in trials lasting ≥6 months, with no difference identified between duration categories. For HbA1c, the corresponding reductions were -0.47% (95% CI, -0.66 to -0.28) in shorter trials and -0.28% (95% CI, -0.62 to -0.06) in longer trials. The authors reported that trial duration did not materially influence improvements in TIR, time in hyperglycemia, or time in hypoglycemia.

Risk of Bias in Included Studies

Of the 11 RCTs included in this review, 2 (18%) were judged to have an overall low risk of bias (14,16), whereas 9 (82%) raised some concerns [13,15,17-23]; none was judged to have a high overall risk of bias. The domain-level risk-of-bias assessments for the included trials are presented in Figure 2. Some concerns arose most often from the randomization process (D1, with allocation-concealment details unconfirmed in 6 of 11 trials) and missing outcome data (D3, with dropout reporting unconfirmed or incomplete in 8 of 11 trials). Deviations from intended interventions (D2) and measurement of the outcome (D4) were considered low risk in nearly all trials. Although participants and clinicians could not be blinded to AID-system allocation, which is an inherent limitation of device-based interventions, the primary outcomes were assessed objectively using CGM or central-laboratory glycated hemoglobin measurements, thereby limiting concerns about detection bias due to lack of blinding. Selective reporting (D5) was considered low risk in most trials, supported by prospective trial registration.

Discussion

This systematic review evaluated randomized evidence on AID in children and adolescents with T1D. Overall, AID consistently improved CGM-derived outcomes, particularly TIR, with more modest improvements in HbA1c. Benefits varied by age, comparator therapy, device platform, and duration of use.

Main Findings and Comparison With the Existing Literature

This systematic review found a consistent improvement in glycemic control with AID systems in children and adolescents with T1D. The most reproducible benefit was an increase in TIR (70-180 mg/dL) across different pediatric age groups and AID platforms. Improvements in HbA1c were generally smaller, indicating that AID may improve daily glucose exposure without producing proportionally large changes in average glycemia.

AID also reduced TAR, supporting better control of hyperglycemia. Improvements in TBR were less consistent, although several trials reported reductions in clinically relevant hypoglycemia. Nighttime glycemic control generally improved more than daytime control, suggesting particular benefit from automated insulin adjustment during periods when active self-management is limited.

The magnitude of benefit varied across studies according to age, baseline glycemic control, comparator therapy, AID platform, and duration of use. Importantly, AID did not completely eliminate hyperglycemia or acute safety events, and treatment remained dependent on appropriate device use and user interaction. Overall, the findings support AID as an effective approach for improving CGM-derived glycemic outcomes, while highlighting remaining variability in HbA1c response and safety outcomes.

The present review demonstrated a consistent improvement in TIR with AID across pediatric RCTs, although the magnitude varied by age, comparator, device, and treatment duration. In the trial by Tauschmann et al. [13], hybrid closed-loop therapy increased TIR by approximately 11 percentage points and reduced HbA1c by 0.36 percentage points compared with sensor-augmented pump therapy. Breton et al. [14] similarly reported an approximately 11-percentage-point increase in TIR, equivalent to about 2.6 additional hours per day in

range.

The findings of Abraham et al. [15] were directionally consistent but showed a smaller between-group TIR difference of 6.7 percentage points (95% CI, 2.7-10.8; $P=0.002$). The study also demonstrated reduced TBR and improved glycemic variability, indicating that increased TIR was not achieved at the expense of greater hypoglycemia.

These individual-trial findings are broadly consistent with previous evidence syntheses. Zeng et al. [6] reported an 11.38-percentage-point increase in TIR (95% CI, 9.01-13.76; $P<0.001$) across 25 trials, with reductions in both TAR and TBR. Michou et al. [7] likewise reported improvements in TIR, hypoglycemia-related outcomes, and HbA1c across pediatric RCTs. More recently, de Visser et al. [8] reported an 11.5-percentage-point increase in TIR (95% CI, 9.3-13.7) and a 0.41-percentage-point reduction in HbA1c (95% CI, -0.58 to -0.25).

An important consistency across the literature is the greater improvement in nocturnal glycemia. de Visser et al. [8] reported a 19.7-percentage-point increase in nighttime TIR, compared with 8.5 percentage points during daytime. This pattern suggests that AID may provide particular benefit during periods when active glucose management is limited. Overall, the present findings are concordant with the existing literature and indicate that the most reproducible effect of AID is improvement in TIR and hyperglycemic exposure, while HbA1c changes are comparatively modest.

Why Time in Range Improves More Consistently Than HbA1c

AID may improve TIR more consistently than HbA1c because its principal effect is to modify the distribution of glucose values throughout the day rather than simply lower the mean glucose concentration. By responding continuously to sensor glucose and its direction of change, an AID algorithm can reduce periods of hyperglycemia and hypoglycemia that contribute directly to TIR without producing a large shift in average glucose. This pattern was observed in the pediatric Cambridge trial and in trials of Control-IQ and other hybrid closed-loop systems [13-16,19].

This distinction is also evident in pooled evidence. Zeng et al. reported an 11.38-percentage-point increase in TIR across pediatric trials [6], while de Visser et al. reported an 11.5-percentage-point increase in TIR but a comparatively smaller 0.41-percentage-point reduction in HbA1c [8]. The greater sensitivity of TIR to changes in daily glucose distribution therefore makes it a complementary outcome to HbA1c rather than a replacement for it. The marked improvement in nighttime TIR reported in the recent meta-analysis [8] further supports the ability of AID to modify glucose exposure during periods of limited active self-management.

What Automated Insulin Delivery Does Not Achieve

AID does not make diabetes management fully autonomous. Most pediatric systems evaluated in these trials are hybrid approaches, meaning that users or caregivers continue to provide meal-related information and respond to device alerts, infusion-set problems, sensor issues, or other interruptions [3,4]. The technology can reduce the frequency and intensity of manual insulin adjustments, but it does not remove the behavioral and practical responsibilities of diabetes care.

AID also does not eliminate hyperglycemia or hypoglycemia. Several trials demonstrated substantial reductions in TAR, yet residual hyperglycemic exposure remained. Severe hypoglycemia and diabetic ketoacidosis were uncommon but were not absent from the evidence base. Interruptions related to pumps, infusion sets, CGM sensors, connectivity, or user factors can also compromise automated delivery. Accordingly, AID should be considered a tool for reducing glycemic burden rather than a completely autonomous treatment, and ongoing education and appropriate user response remain necessary [3,4,8].

However, the distinction between hybrid and fully closed-loop (FCL) systems is becoming increasingly important. Emerging FCL approaches are specifically designed to address one of the major residual limitations of current pediatric AID: dependence on user-entered meal information. In a randomized crossover trial of 18 adolescents with T1D, an advanced fully automated system that delivered automatic prandial insulin following unannounced meals achieved substantially greater postprandial TIR than a hybrid closed-loop comparator (83% vs 53% during the 6 hours following an unannounced meal), without increasing TBR [25]. More recently, a two-center randomized crossover trial involving 24 adolescents aged 13-19 years with above-target HbA1c demonstrated that FCL insulin delivery using faster insulin aspart increased TIR by 12.9 percentage points compared with standard insulin pump therapy with CGM (45.2% vs 32.3%), while TBR was similar, and no severe hypoglycemia or diabetic ketoacidosis occurred [26]. These findings provide direct pediatric evidence that FCL systems can reduce reliance on carbohydrate counting and improve glycemic exposure, although the relatively small sample sizes and limited duration of these studies preclude concluding that meal-free insulin delivery is yet equivalent to established long-term pediatric AID practice.

The transition toward FCL systems will require algorithms capable of distinguishing meal-related glucose excursions from other sources of glycemic variability and delivering sufficiently rapid insulin responses despite the pharmacokinetic limitations of subcutaneous insulin. Thus, future systems are likely to depend not only on more sophisticated prediction and control algorithms but also on faster insulin formulations and additional physiological inputs.

Influence of Age, Technology, and Context on the Magnitude of Benefit

AID benefit was observed across the pediatric age range, including very young children, but effect sizes were not uniform. Ware et al. reported an 8.7-percentage-point TIR improvement in their young-child cohort, while Wadwa et al. reported a larger effect in children aged 2 to younger than 6 years using Control-IQ [9,10]. These differences should be interpreted in relation to baseline glycemia, comparator therapy, duration, and device characteristics rather than as direct evidence that one age group responds better than another.

The extent of automation may also influence outcomes. In a randomized study of prepubertal children, 24/7 Control-IQ activation increased TIR by 14.4 percentage points compared with 9.6 percentage points with evening/night activation; automation was active for 94.1% versus 51.1% of the respective periods [27]. This supports the importance of sustained automated exposure, although direct comparisons between AID platforms remain inappropriate because algorithms, glucose targets, sensors, pumps, and user requirements differ substantially.

The composition of the insulin formulation may also influence how effectively AID responds to rapid postprandial glucose excursions. Faster-acting insulin aspart has pharmacokinetic advantages over standard insulin aspart in children and adolescents, including earlier appearance and greater early insulin exposure [28]. Nevertheless, clinical superiority within AID has not been consistently demonstrated. In a double-blind randomized crossover trial of 30 active children and adolescents, both faster insulin aspart and standard insulin aspart used with hybrid AID reduced TAR substantially from baseline, but there was no significant between-treatment difference in TAR [29]. These findings suggest that faster insulin formulations may facilitate more responsive closed-loop control but should not be assumed to provide an independent glycemic advantage across all pediatric AID settings.

Multihormonal systems represent another strategy for overcoming limitations of insulin-only control. In a randomized crossover study of 19 preadolescent children aged 6–11 years, a bihormonal bionic pancreas delivering both insulin and glucagon produced lower mean glucose and less time at very low glucose concentrations than conventional insulin pump therapy [30]. However, the incremental benefit of glucagon over insulin-only closed-loop therapy is not consistently demonstrated. In an inpatient randomized crossover study of 11 adolescents, dual-hormone and single-hormone closed-loop systems produced broadly similar overall glycemic outcomes, and the single-hormone configuration performed better during the overnight and exercise periods [31]. Thus, glucagon-based systems remain promising but require further pediatric evaluation to determine which clinical circumstances justify the additional hormonal component.

Pramlintide provides a different approach by slowing gastric emptying and suppressing postprandial glucagon secretion, potentially reducing the mismatch between nutrient absorption and subcutaneous insulin action. In a randomized crossover trial including 15 adolescents and 15 adults, an insulin-pramlintide closed-loop system using simple meal announcements achieved non-inferior TIR compared with an insulin-only system requiring carbohydrate counting [32]. However, gastrointestinal symptoms were more frequent with pramlintide, and the mixed-age design limits extrapolation of the findings to children and adolescents alone. Consequently, pramlintide-enabled AID should currently be regarded as a promising strategy for reducing carbohydrate-counting burden rather than an established pediatric standard.

Safety and Patient-Reported Outcomes

Across the pediatric randomized trials, higher TIR was generally achieved without a consistent increase in hypoglycemia. Abraham et al. reported a 1.9-percentage-point reduction in time below 70 mg/dL with no severe hypoglycemia or diabetic ketoacidosis in either group [15]. Ware et al. similarly found no significant increase in hypoglycemic exposure despite improved TIR [9]. Rare events remain difficult to quantify from individual trials; the larger evidence synthesis by de Visser et al. identified 19 severe-hypoglycemia events and 8 diabetic ketoacidosis events among 841 participants [8]. These findings reinforce the need for larger populations and longer surveillance when evaluating uncommon adverse events.

Patient-reported outcomes remain less extensively studied than CGM metrics. Abraham et al. reported a 4.4-point improvement in diabetes-specific quality of life, but diabetes distress did not significantly change [15]. Thus, better glycemic control should not automatically be equated with reduced treatment burden, particularly because AID still requires device management, troubleshooting, and user input.

Clinical and Public Health Implications

The clinical importance of the evidence lies primarily in the repeated improvement in TIR and reduction in hyperglycemic exposure across pediatric AID trials. An increase of approximately 10-12 percentage points in TIR corresponds to about 2.4-2.9 additional hours per day within the target range, which represents a clinically meaningful change in daily glucose exposure.

Translation into routine care may nevertheless differ from trial efficacy. Sustained AID use depends on access to CGM sensors, insulin, infusion sets, pumps, technical support, and appropriate education. Current ISPAD guidance emphasizes individualized technology selection, education, and continuing support [3,4]. Implementation decisions should therefore consider affordability, availability, caregiver capacity, and continuity of supplies in addition to the efficacy demonstrated under trial conditions.

Strengths of the Current Evidence

A major strength is the convergence of findings across randomized outpatient trials, including different pediatric age groups and AID platforms [9,13-23]. The evidence also increasingly incorporates CGM-derived outcomes such as TIR, TBR, and TAR alongside HbA1c, providing a more detailed assessment of glycemic exposure.

Importantly, improvements in TIR were generally accompanied by stable or reduced TBR, indicating that the increase in target-range glucose was not consistently achieved at the expense of greater hypoglycemia [6,8]. The consistency of this pattern across different technologies strengthens the evidence for a class-level benefit of AID.

Limitations and Remaining Evidence Gaps

The main methodological limitation is that AID trials are typically open-label because participants and clinicians can see the assigned technology. de Visser et al. identified important risk-of-bias concerns in some pediatric trials, including limitations related to blinding and, in some studies, the handling of intention-to-treat analyses [8]. In the present review, these issues were considered alongside the objective nature of the principal CGM and HbA1c outcomes.

Clinical heterogeneity is another important limitation. Trials differed in age, baseline HbA1c, diabetes duration, comparator therapy, AID platform, and intervention duration, limiting direct comparison of effect sizes across studies. Evidence is also stronger for short- to medium-term glycemic outcomes than for long-term clinical outcomes, treatment persistence, caregiver burden, and quality of life [8]. Patient populations were additionally insufficiently diverse in several trials, limiting generalizability across different socioeconomic and ethnic settings.

Rare adverse events remain difficult to estimate from individual RCTs because of limited sample sizes. Larger real-world cohorts and longer surveillance are therefore needed to complement randomized evidence, particularly for DKA and technology-related adverse events.

The evidence base for emerging FCL, multihormonal, and wearable-integrated systems is even less mature. Many studies remain small, short in duration, inpatient or highly supervised, and technically heterogeneous. In particular, evidence for wearable-integrated AID should not be assumed to be pediatric evidence. A randomized trial integrating real-time heart-rate and accelerometry data from a smartwatch into an exercise-aware AID system demonstrated feasibility and favorable glycemic outcomes in adults, but the study population was aged 21-50 years [33]. Pediatric translation therefore remains an important evidence gap.

Future Research Priorities

Future studies should address not only whether AID improves TIR but also which children benefit under specific clinical and social conditions and whether these gains translate into durable health outcomes. Longer follow-up should include standardized patient-reported outcomes, treatment burden, school participation, physical activity, device discontinuation, adherence, and technology-related adverse events.

Additional research is needed in very young children, socioeconomically diverse populations, and settings where access to diabetes technology is limited [8]. Future comparative studies should consistently report TIR, TBR, TAR, HbA1c, automation exposure, and adverse events to facilitate interpretation across platforms and populations. The current evidence supports continued evaluation of AID as a component of pediatric T1D care, with particular emphasis on long-term clinical, psychosocial, and health-system outcomes.

Future research should also move toward genuinely context-aware FCL systems that integrate CGM dynamics with meal detection, physical activity, and other physiological signals. Heart-rate-informed AID has already shown a clinically relevant reduction in time below 70 mg/dL during exercise in adolescents,

from 7.4% with a conventional artificial pancreas configuration to 0.5% with heart-rate-informed control [34]. More recently, an exercise-aware AID platform integrating heart rate and accelerometry from a smartwatch demonstrated the feasibility of using wearable-derived exercise metrics as continuous inputs to automated insulin dosing, although this evidence remains limited to adults [32]. Computational approaches using accelerometry, heart rate, and activity duration have also demonstrated the feasibility of classifying aerobic, interval, and resistance exercise, potentially allowing future algorithms to anticipate rather than merely react to exercise-associated glucose changes [35]. Importantly, recent pediatric exercise data show that hypoglycemia can still occur despite contemporary AID systems, underscoring the need for predictive exercise-aware algorithms rather than reliance solely on reactive CGM-based control [35].

Taken together, the next generation of pediatric AID is likely to evolve from glucose-responsive hybrid systems toward fully automated, multimodal control. The combination of more rapid insulin kinetics, advanced predictive algorithms, adjunctive hormones such as glucagon or pramlintide, and wearable-derived physiological information could progressively reduce the need for manual meal and exercise inputs. However, each component remains at a different stage of clinical development, and larger pediatric trials with longer follow-up are required before these approaches can be considered routine alternatives to current hybrid AID systems.

Conclusions

This systematic review of 11 RCTs demonstrates a consistent benefit of AID systems for glycemic management in children and adolescents with T1D. Across different technologies and pediatric age groups, the most reproducible finding was an improvement in TIR, generally of approximately 7–12 percentage points, corresponding to roughly 2.4–2.9 additional hours per day within the target range. Improvements in HbA1c were comparatively modest, while reductions in hyperglycemic exposure were generally observed without increased CGM-defined hypoglycemia.

AID may provide particular benefit during nighttime, but current pediatric systems remain predominantly hybrid and therefore still require meal-related input, device management, and patient or carer engagement. Hyperglycemia, hypoglycemia, and technology-related interruptions are not completely eliminated, while rare outcomes such as severe hypoglycemia and diabetic ketoacidosis remain insufficiently characterized because of limited trial sizes. Heterogeneity in age, baseline glycemia, comparator therapy, device algorithms, and treatment duration also limits direct comparison between platforms.

Emerging evidence suggests a transition toward FCL and context-aware AID, with faster-acting insulin formulations, multihormonal approaches, and wearable-derived physiological signals potentially reducing dependence on manual meal and exercise management. However, these approaches remain at different stages of development, and pediatric evidence is still limited for several technologies.

Overall, current randomized evidence supports AID as an important technology for improving day-to-day glycemic control in pediatric T1D. Future research should prioritize longer-term evaluation of FCL and multimodal systems, standardized psychosocial and treatment-burden outcomes, broader representation of underserved populations, and adequately powered assessment of rare adverse events and technology-related complications.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Rakhi Jain, Piyush Upadhyay

Acquisition, analysis, or interpretation of data: Rakhi Jain, Piyush Upadhyay

Drafting of the manuscript: Rakhi Jain, Piyush Upadhyay

Critical review of the manuscript for important intellectual content: Rakhi Jain, Piyush Upadhyay

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other relationships or activities that could appear to have influenced the submitted work.

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