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Optimal Glucose Management Using Advanced Hybrid Systems in Type 1 Diabetes: Extended Meta-Analysis Comparing Control-IQ, Medtronic, and the iLet Bionic Pancreas

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Abstract

Background: Type 1 diabetes mellitus (T1DM) requires lifelong insulin therapy to maintain glycemic control and prevent complications. Hybrid closed-loop (HCL) systems, including the iLet® bionic pancreas, Control-IQ®, and Medtronic MiniMed™ devices, integrate continuous glucose monitoring (CGM) with algorithm-driven insulin delivery to improve glycemic outcomes, yet comparative evidence is limited.

Methods: We conducted a systematic review and meta-analysis of randomized controlled trials evaluating advanced automated insulin delivery systems in T1DM. PubMed, Web of Science, and Scopus were searched up to 1 January 2026. Primary outcomes included changes in glycated hemoglobin (HbA1c) and CGM-derived metrics such as time-in-range (70–180 mg/dL), time in hypoglycemia (<70 and <54 mg/dL), and hyperglycemia (>180 and >250 mg/dL). Secondary outcomes included glycemic variability and adverse events. Standardized mean differences (SMD) and odds ratios (OR) with 95% confidence intervals (CI) were pooled using random-effects models. Risk of bias was assessed with the Cochrane RoB 2.0 tool.

Results: Thirty-three RCTs comprising adults and pediatric patients were included. Use of the iLet bionic pancreas significantly reduced HbA1c (SMD −0.50; 95% CI −0.63 to −0.38) and mean CGM glucose (SMD −0.36; 95% CI −0.50 to −0.21), while increasing time-in-range (SMD 0.58; 95% CI 0.43–0.73) without significant increases in hypoglycemia (<70 mg/dL: SMD −0.01; <54 mg/dL: SMD −0.11). Medtronic MiniMed™ 780G also improved HbA1c (MD −1.05; 95% CI −1.62 to −0.49) and TIR, whereas 670G showed minimal HbA1c change (MD −0.07; 95% CI −0.55 to 0.41). Adverse events were slightly higher with iLet but severe hypoglycemia and diabetic ketoacidosis rates were not significantly different.

Conclusions: Advanced HCL systems, particularly the iLet bionic pancreas and MiniMed™ 780G, improve glycemic control and time-in-range in T1DM with minimal hypoglycemia risk. These findings support their clinical utility in optimizing automated insulin delivery and reducing patient burden.

Keywords: iLet Bionic Pancreas; Type 1 Diabetes.

List of Abbreviations

AID – Automated Insulin Delivery

CGM – Continuous Glucose Monitoring

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CV – Coefficient of Variation

DKA – Diabetic Ketoacidosis

HCL – Hybrid Closed-Loop (insulin delivery system)

HbA1c – Glycated Hemoglobin

iLet – iLet® Bionic Pancreas

MD – Mean Difference

MDI – Multiple Daily Injections

OR – Odds Ratio

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

RCT – Randomized Controlled Trial

SD – Standard Deviation

SH – Severe Hypoglycemia

T1DM – Type 1 Diabetes Mellitus

TIR – Time-in-Range (70–180 mg/dL)

Introduction

Type 1 diabetes mellitus (T1DM) necessitates lifetime insulin therapy in order to establish glycemic control and avoid both acute and chronic consequences. Maintaining ideal glycemic targets is still difficult despite advancements in insulin formulations and glucose monitoring technologies; plenty of individuals fall below the threshold of recommended glycated hemoglobin (HbA1c) levels while encountering a serious risk of hypoglycemia and glycemic variability [1,2]. Although real-time glucose awareness has improved with continuous glucose monitoring (CGM), patients still face significant cognitive and behavioral challenges when converting glucose data into the proper insulin adjustments [3].

A significant development in the treatment of diabetes is the use of hybrid closed-loop (HCL) insulin delivery systems, which combine automated insulin administration algorithms with CGM data to dynamically modify insulin dosage. These systems seek to improve overall glycemic stability, decrease exposure to hypoglycemia and hyperglycemia, and extend the amount of time spent in the target glycemic range (70–180 mg/dL) [4]. The computational techniques, level of automation, and dependence on user input of a number of commercially available HCL systems vary, which may have an impact on both safety and efficacy results. A highly automated method of delivering insulin, the iLet® bionic pancreas (iLet), uses an adaptive algorithm that requires little user input other than initializing body weight. Without the need for user-directed bolus calculations or carbohydrate counting, insulin dosage is continuously modified in response to CGM patterns. When compared to conventional care, clinical trials have shown that iLet significantly lowers HbA1c, improves time-in-range, and reduces glycemic variability, indicating that less user load may result in more consistent glycemic outcomes [5-7].

The Control-IQ hybrid closed-loop system, on the other hand, requires user-initiated meal boluses but uses a predictive control algorithm to regulate basal insulin supply and administer automated corrective boluses. Control-IQ has a good safety profile, a low incidence of severe hypoglycemia, and a significant improvement in HbA1c and duration in range while lowering hyperglycemia, according to randomized controlled trials [8–10]. This approach may be widely adopted since it strikes a balance between automation and patient involvement.

The MiniMedTM 670G and the more sophisticated MiniMedTM 780G are examples of Medtronic hybrid closed-loop systems that represent both earlier and later generations of automated insulin delivery. Although its effects on HbA1c were inconsistent, the 670G system, one of the first commercially available HCL devices, showed small increases in time-in-range and hypoglycemia reduction [11]. In clinical trials, the MiniMedTM 780G has demonstrated better improvements in glycemic outcomes thanks to algorithmic innovations such automatic correction boluses and lower glucose targets [12,13]. Nonetheless, variations in reported efficacy among studies point to possible variations in practical performance. A comparative synthesis of the current information is crucial due to the variation in system design, automation level, and clinical outcomes. With a focus on important glycemic outcomes like HbA1c, time-in-range, hypoglycemia, hyperglycemia, glycemic variability, and adverse events, this systematic review and meta-analysis attempts to assess and compare the effectiveness and safety of iLet, Control-IQ, and Medtronic hybrid closed-loop systems in people with T1DM.

Methods

Study Design and Protocol:

We conducted a systematic review and meta-analysis according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (5). The study is registered in OSF with the following DOI: 10.17605/OSF.IO/QTDXV.

Data source and search strategy

We conducted a broad literature search to identify studies on iLet bionic pancreas. To assess the evidence for this purpose, a broad search for clinical trials was initiated through PubMed (including MEDLINE records), Web of Science, and Scopus databases for the trials published up to 1 January 2026, by two independent authors. The electronic search strategy included both Medical Subject Headings (MeSH) and keywords (free text words). Search terms included the keyword terms “iLet”, “Bionic pancreas”,“ Artificial

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pancreas". Any discrepancies (if present) were resolved by a third author. The study was limited to human subjects and the articles were written in English. The literature was managed, and duplicates were removed using EndNote X7 software. The reference lists and topic-related reviews were manually checked to identify relevant papers. Further details on search strategy is given in Table 4.

Study selection, inclusion, and exclusion criteria

Randomised control trials (RCTs) were included. Studies were not included if they were case reports, reviews, letters, or conference abstracts without a full text. One author screened the titles and abstracts of the full text. Any disagreements were resolved by the fourth author. All the included studies represented unique trials. We used the PICO (Patient/ Population, Intervention, Comparison, and Outcomes) framework to establish the following inclusion criteria for all relevant original articles:

Population: Patients diagnosed with Type 1 Diabetes Mellitus (T1DM) of any age or gender who require insulin therapy for glycemic control. The inclusion of participants using conventional insulin delivery methods as a comparator was noted.

Intervention: The interventions of interest were advanced automated insulin delivery (AID) systems, including the insulin-only iLet® bionic pancreas and commercially available hybrid closed-loop (HCL) systems. These included Control-IQ® technology (Tandem t:slim X2) and Medtronic MiniMed™ systems (670G and 780G), which integrate continuous glucose monitoring with algorithm-driven insulin delivery. The level of automation varied across systems, ranging from fully autonomous insulin dosing with minimal user input (iLet) to hybrid systems requiring user-initiated meal boluses alongside automated basal insulin modulation.

Comparison

Standard care, which is defined as traditional insulin delivery methods such multiple daily injections (MDI) or standard insulin pump therapy, with or without continuous glucose monitoring (CGM), was contrasted with the effectiveness and safety of the iLet bionic pancreas. Unlike the iLet system, normal care necessitated manual insulin dose modifications depending on physical activity, carbohydrate consumption, and glucose readings. All of the included studies used this definition in the same way.

Outcomes: Primary outcomes included changes in glycated hemoglobin (HbA1c) and continuous glucose monitoring (CGM) metrics, such as time spent in different glucose ranges (e.g., hypoglycemia, euglycemia, and hyperglycemia). Additional primary measures will include the coefficient of variation (CV) and standard deviation (SD) of glucose levels to assess glycemic variability. Secondary outcomes included any adverse events, events of hypoglycemia and events of diabetic ketoacidosis.

Details of each outcomes measured are as follows:

Primary outcomes:

HbA1c: One of the primary glycemic outcomes assessed was the change in glycated hemoglobin (HbA1c) from baseline to 13 weeks of follow-up. HbA1c was measured using standard laboratory assays at study initiation (pre-intervention) and again at the end of the 13-week study period (post-intervention) for both the iLet Bionic Pancreas (intervention) and standard care (control) groups. The mean difference (MD) between the baseline and post-intervention HbA1c values was calculated within each iLet Bionic Pancreas and Standard care group, and comparison was performed between them by plotting standard mean difference in forest plots.

Time-in-range foreuglycemic range (70-180 mg/dL): time-in-range (TIR), defined as the percentage of time that glucose values remained within the target range of 70–180 mg/dL, was a key continuous glucose monitoring (CGM)-derived outcome used to assess glycemic control. CGMs (Dexcom G6) provide real-time interstitial glucose data and were worn by all participants throughout the study. CGM devices measured glucose values every 5 minutes, yielding up to 288 readings per day. These high-frequency data were used to ensure stable glycemic patterns and to cross-validate trends associated with HbA1c changes. Participants in both groups maintained ≥80% CGM data capture during the 13-week study period, ensuring reliability in comparing mean glucose levels and other CGM-derived metrics. TIR was calculated using data obtained from CGM devices worn by participants in both the iLet Bionic Pancreas (intervention) and standard care (control) groups. Baseline TIR was established using CGM data collected during the run-in or preoperative phase. At the end of the 13-week intervention period, post-treatment TIR was again assessed using CGM data collected over the final 1–2 weeks of the study. The mean difference in TIR from baseline to follow-up was calculated for each group, and comparison was performed between them by plotting standard mean difference in forest plots.

Time spent in hypoglycemia and hyperglycemia: Additional glycemic outcomes included the percentage of time spent in hypoglycemia (glucose <70 mg/dL and <54 mg/dL) and hyperglycemia (glucose >180 mg/dL and >210 mg/dL), derived from continuous glucose monitoring (CGM) data. These outcomes were calculated from CGM readings collected using the Dexcom G6 system, which captured interstitial glucose levels every 5 minutes, providing granular data for daily glucose excursions. The mean difference in time spent in each glucose range <54 mg/dL, <70 mg/dL, >180 mg/dL,>210 mg/dL from baseline to follow-up was

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calculated for each group, and comparison was performed between them by plotting standard mean difference in forest plots.

Secondary outcomes:

Glycemic Variability

Glycemic variability was assessed using the standard deviation (SD) and coefficient of variation (CV) derived from continuous glucose monitoring data. Compared with standard care, use of the iLet bionic pancreas was associated with a significant reduction in glucose SD (SMD −0.39; 95% CI: −0.53 to −0.24; $p < 0.00001$; $I^2 = 0\%$) and CV (SMD −0.20; 95% CI: −0.35 to −0.06; $p = 0.006$; $I^2 = 0\%$), indicating more stable glucose profiles (Figures S8 and S9).

Safety Outcomes

The incidence of any reported adverse events was higher in the iLet group compared with standard care (OR 15.48; 95% CI: 8.07–29.70; $p < 0.00001$; $I^2 = 41\%$) (Figures S10 and S15). In contrast, no statistically significant differences were observed between groups for severe hypoglycemia (OR 2.22; 95% CI: 0.83–5.94; $p = 0.11$; $I^2 = 0\%$) or diabetic ketoacidosis (OR 2.42; 95% CI: 0.11–51.33; $p = 0.57$) (Figures S11 and S12).

Screening and Data extraction:

Two independent reviewers initially screened the titles and abstracts of identified records for eligibility, followed by full-text assessment of potentially relevant studies. Data extraction was conducted independently by two authors using a standardized Excel spreadsheet, with discrepancies resolved through discussion with a third reviewer. A standardized data extraction form was used to collect information on study characteristics (including first author, year of publication, sample size, patient population, and degree of change in each outcome) and outcome measures. Extracted outcomes included HbA1c, continuous glucose monitoring (CGM) metrics, and the percentage of time blood glucose levels were within specified ranges: >210 mg/dL, >180 mg/dL, 70–180 mg/dL, <70 mg/dL, and <54 mg/dL. Additional CGM-derived measures, such as the coefficient of variation and standard deviation of glucose values, were also recorded. Furthermore, data on adverse events, including hypoglycemic episodes and diabetic ketoacidosis (DKA) events, were systematically extracted. In cases where multiple publications reported on the same dataset, duplicate entries were removed to prevent overestimation of findings.

Data synthesis and statistical analysis

We pooled the results of the meta-analysis for each outcome only if a minimum of two trials reported an outcome. Statistical analysis was performed using OpenMeta Analyst Software and Review Manager (Version 5.4; The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen). If data were reported as median (range or interquartile range), we converted them to mean and standard deviation using the Wan formula (12) to convert data to mean and standard deviation. The pooled proportion was estimated for changes in HbA1c and CGM levels using the mean difference (MD) or odds ratio (OR). using the Mantel-Haenszel test, with 95% confidence interval (CI) for continuous and categorical variables, respectively. Only variables reported in at least two studies were analysed. A random-effects model was used to calculate the pooled estimates and 95% confidence intervals. The I^2 index indicated heterogeneity across the studies. The value of I^2 between 25% and 50% indicated mild heterogeneity, between 50% and 75% indicated moderate heterogeneity, and greater than 75% indicated severe heterogeneity. Potential publication bias was assessed using the Begg's correlation test. Statistical significance was set at $P < 0.05$.

Risk of bias assessment:

The methodological quality of each included study was evaluated independently by two authors. The Revised Cochrane Risk-of-Bias Tool (RoB 2.0) was used to evaluate the risk of bias because the included trials were prospective comparative studies with randomized designs. Bias resulting from randomization, changes from planned interventions, missing outcome data, outcome measurement, and selective reporting were all assessed. Consensus was used to settle disagreements. The overall risk of bias at the study level was classified as low, significant concerns, or high.

Results

Study selection:

A systematic search of PubMed, Web of Science, and Scopus up to 1 January 2026 identified 2,405 records. A total of 2,405 records were identified through database searches. Prior to screening, 847 records were removed: 786 duplicates, 57 flagged by automation tools, and 4 for other reasons. This left 1,562 records for screening, of which 587 were excluded Of the 975 reports sought for retrieval, 7 were not retrieved, leaving 968 reports for eligibility assessment. During this stage, 935 reports were excluded: 927 did not meet the PICO requirements, 3 were case reports, and 5 were cross-sectional studies. Ultimately, 33 randomized controlled trials evaluating automated insulin delivery systems in individuals with type 1 diabetes were included in the qualitative and quantitative synthesis. Study selection is shown in Figure S16. Characteristics of included studies are given in Table 1.

Study Characteristics:

A total of 33 studies were included in the analysis, all conducted as multicenter randomized controlled trials (RCTs), with one study (Lynch et al., 2022) being a single-arm extension. The population across studies included both

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adults (aged 18–79 years) and youth (aged 6–17 years) with type 1 diabetes mellitus (T1DM). Sample sizes varied, ranging from 90 to 324 participants. The intervention in all studies included : the use of the iLet bionic pancreas system, either as monotherapy or alongside continuous glucose monitoring (CGM) the Tandem Control-IQ® technology, and the Medtronic MiniMed™ 670G and 780G systems. The comparator across most trials was standard care with usual insulin delivery, often supplemented with CGM. The follow-up duration in all studies was 13 weeks. Key outcomes assessed included change in glycated hemoglobin (HbA1c), time-in-range (TIR), time spent in hypoglycemia (<70 mg/dL or <54 mg/dL), and incidence of adverse events including severe hypoglycemia (SH) and diabetic ketoacidosis (DKA). The iLet system consistently demonstrated reductions in HbA1c (by approximately 0.5–0.6%), increases in TIR, and minimal increases in hypoglycemia or adverse event rates across both adult and pediatric populations, with some studies highlighting improvements across racial and ethnic groups.

Changes in outcomes:

For all continuous outcomes, standardized mean differences (SMDs) were calculated with standard care as the reference group, while odds ratios (ORs) for safety outcomes represent event occurrence in the iLet group relative to standard care.

Analysis of Primary Outcomes

Analysis of iLet Hybrid Closed-Loop Systems

Glycemic Control Outcomes

HbA1c: The iLet group demonstrated a greater reduction in HbA1c compared with Standard Care. The pooled mean difference (MD) was [−0.49%; 95% CI: −0.64 to −0.34; p<0.0001], (I^2 = 0%) (Figure S1). This finding indicates a statistically significant and consistent improvement in long-term glycemic control with iLet compared with Standard Care.

Mean Glucose Levels: Mean glucose levels were reduced to a greater extent in the iLet group compared with Standard Care . Meta-analysis showed a pooled MD of [−0.36 mg/dL; 95% CI: −0.50 to −0.21; p <0.00001], with (I^2 = 0%) (Figure S2).These results demonstrate a robust and homogeneous reduction in average glucose levels favoring iLet therapy.

Time for Glycemic Ranges

Hypoglycemia: The pooled MD for glucose levels <54 mg/dL was [−0.11; 95% CI: −0.26 to 0.04; p = 0.14], with I^2 = 0% (Figure S3). This suggests no statistically significant difference between iLet and Standard Care in exposure to severe hypoglycemia.

Similarly, time spent <70 mg/dL showed a pooled MD of [−0.03; 95% CI: −0.17 to 0.12; p = 0.72], with I^2 = 0%, favoring the iLet group (Figure S4). These findings indicate comparable rates of mild hypoglycemia between treatment strategies. time-in-range (70–180 mg/dL) The pooled MD was [0.48; 95% CI: 0.53 to 0.73; p<0.00001], with I^2 = 0% (Figure S5).This reflects a significant and consistent increase in time spent within the optimal glycemic range among patients using iLet.

Hyperglycemia

Time spent with glucose levels >180 mg/dL was reduced in the iLet group, with a pooled MD of [−0.52; 95% CI: −0.67 to −0.37; p<0.00001] and I^2 = 0% (Figure S6).This demonstrates a substantial reduction in hyperglycemic exposure with iLet therapy. For glucose levels >250 mg/dL, the pooled MD was [−0.33%; 95% CI: −0.47 to −0.18; p<0.0001], with I^2 = 0%, indicating consistent effects across studies (Figure S7). These results further support improved control of severe hyperglycemia in the iLet group.

Glycemic Variability: Glucose standard deviation was lower in the iLet group, with a pooled standardized mean difference (SMD) of [−0.39; 95% CI: −0.53 to −0.24; p <0.00001], and I^2 = 0% (Figure S8). This suggests that iLet use is associated with more stable glucose profiles.

Similarly, coefficient of variation was reduced, with a pooled SMD of [−0.20; 95% CI: −0.35 to −0.06; p = 0.006], and I^2 = 0% (Figure S9). These findings indicate a consistent reduction in glycemic variability with iLet compared to Standard Care.

Safety Outcomes

Adverse Events: The pooled odds ratio (OR) for any adverse events in iLet BP group as compared to Co trol group was [OR = 15.48; 95% CI: 8.07–29.70; p <0.00001], with I^2 = 41% (Figures S10 and S15). This suggests a higher overall incidence of reported adverse events in the iLet group, with moderate between-study heterogeneity.

Severe Hypoglycemia and Diabetic Ketoacidosis: Severe hypoglycemia showed a pooled OR of [OR = 2.22; 95% CI: 0.83–5.94; p = 0.11], with I^2 = 0% (Figure S11). This indicates no statistically significant difference in severe hypoglycemia between the two groups.

Diabetic ketoacidosis showed a pooled OR of [OR = 2.42; 95% CI: 0.11–51.33; p = 0.57] (Figure S12). These results suggest no significant difference in the risk of diabetic ketoacidosis between iLet and Standard Care.

Summary of all the outcomes is given in Table 2.

Analysis of Medtronic Hybrid Closed-Loop Systems

Glycemic Control: HbA1c

HbA1c levels were assessed at baseline and at the end of follow-up in studies evaluating the Medtronic MiniMed™

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670G hybrid closed-loop system. The pooled analysis showed no significant difference in HbA1c reduction between participants using the 670G system and those receiving standard care (MD −0.07; 95% CI −0.55 to 0.41; p = 0.78), with substantial heterogeneity among studies (I^2 = 85%) (this is shown in Figure S27).

The MiniMed™ 780G advanced hybrid closed-loop system demonstrated a reduction in HbA1c compared with control therapy (MD −1.05; 95% CI −1.62 to 0.49; p = 0.0003), with low heterogeneity (I^2 = 4%) (shown in Figure S28).

time-in-range (70–180 mg/dL)

The percentage of time spent in the target glucose range (70–180 mg/dL) was higher among participants using Medtronic hybrid closed-loop systems. Compared with standard care, the MiniMed™ 670G system significantly increased time-in-range (MD 0.67; 95% CI 0.34 to 1.00; p < 0.0001), with substantial heterogeneity observed across studies (I^2 = 74%) (this is shown in Figure S25).

A greater improvement in time-in-range was observed with the MiniMed™ 780G system. The pooled analysis demonstrated a significant increase in TIR compared with control therapy (MD 1.71; 95% CI 1.14 to 2.28; p < 0.00001), despite considerable heterogeneity (I^2 = 92%) (shown in Figure S26).

Time for Hypoglycemia

<54 mg/dL

The MiniMed™ 670G system was associated with a significant reduction in time spent with glucose levels below 54 mg/dL compared with standard care (MD −0.56; 95% CI −1.06 to −0.07; p = 0.03), although substantial heterogeneity was present (I^2 = 82%) (this is shown in Figure S31).

Similarly, use of the MiniMed™ 780G system resulted in a significant reduction in clinically significant hypoglycemia (MD −0.37; 95% CI −0.62 to −0.11; p = 0.005), with high heterogeneity among included studies (I^2 = 71%) (as appears in figure S32).

<70 mg/dL

Participants using the MiniMed™ 670G system experienced a significant reduction in time spent below 70 mg/dL compared with control therapy (MD −0.91; 95% CI −1.19 to −0.63; p = 0.00001), with moderate heterogeneity (I^2 = 53%) (this is shown in Figure S29). The MiniMed™ 780G system also significantly reduced time spent below range (MD −0.50; 95% CI −0.91 to −0.10; p = 0.01), with considerable heterogeneity across included studies (I^2 = 86%) (this is shown in Figure S30).

Time for Hyperglycemia

>180 mg/dL

No significant difference in time spent above 180 mg/dL was observed between participants using the MiniMed™ 670G system and those receiving standard care (MD −0.10; 95% CI −0.75 to 0.54; p = 0.75), with substantial heterogeneity (I^2 = 87%) (this is shown in Figure S33).

In contrast, the MiniMed™ 780G system was associated with a significant reduction in time above range compared with control therapy (MD −1.37; 95% CI −1.86 to −0.87; p < 0.00001), with high heterogeneity (I^2 = 89%) (this is shown in Figure S34).

>250 mg/dL

The MiniMed™ 670G system did not significantly reduce time spent in severe hyperglycemia (>250 mg/dL) compared with standard care (MD −0.08; 95% CI −0.78 to 0.63; p = 0.83), with considerable heterogeneity observed (I^2 = 89%) (this is shown in Figure S35).

Similarly, the MiniMed™ 780G system demonstrated a significant decrease in time spent above 250 mg/dL compared with control therapy (MD −1.57; 95% CI −2.24 to −0.90; p < 0.00001), indicating effective limitation of severe hyperglycemic excursions, despite substantial heterogeneity (I^2 = 91%) (this is shown in Figure S36).

Analysis of Control-IQ Hybrid Closed-Loop System

Glycemic Control: HbA1c

HbA1c levels were assessed at baseline and at the end of follow-up in studies evaluating the Control-IQ hybrid closed-loop system. The pooled analysis demonstrated a significantly greater reduction in HbA1c in participants using Control-IQ compared with standard care. The standardized mean difference (SMD) in HbA1c reduction was −0.40 (95% CI: −0.58 to −0.22; p < 0.0001; I^2 = 37%). Control-IQ significantly improves long-term glycemic control as reflected by a meaningful reduction in HbA1c (this is shown in Figure S20).

time-in-range (70–180 mg/dL)

The percentage of time spent in the target glucose range (70–180 mg/dL) was significantly higher in participants using Control-IQ. Compared with standard care, Control-IQ significantly increased time-in-range (SMD 0.89 (95% CI: 0.72 to 1.07; p < 0.00001; I^2 = 43%)) shown in. Control-IQ markedly increases daily time spent in the euglycemic range, indicating improved glycemic stability. This is shown in Figure S19.

Time for Hypoglycemia

<54 mg/dL

No significant difference was observed in the percentage of time spent with glucose levels below 54 mg/dL between the Control-IQ group and the standard care group (SMD −0.56 ,

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95% CI: −0.73 to −0.39; p < 0.00001; I^2 = 0%) . Therefore, control-IQ does not increase the risk of clinically significant hypoglycemia. An I^2 value of 62% indicated moderate heterogeneity among studies. This is shown in Figure S22.

<70 mg/dL

The pooled analysis showed a reduction in time spent below 70 mg/dL with Control-IQ compared with standard care −0.81 (95% CI: −1.06 to −0.57; p < 0.00001; I^2 = 46%) significantly reducing mild hypoglycemia compared with standard care. Low heterogeneity was observed among the included studies (I^2 = 4%). This is shown in Figure S21.

Time for Hyperglycemia

>180 mg/dL

The percentage of time spent in hyperglycemia (>180 mg/dL) was significantly reduced in participants using Control-IQ. The pooled analysis demonstrated a marked decrease compared with standard care (SMD −0.37 95% CI: −0.81 to 0.08; p = 0.11; I^2 = 84%). This reflects control-IQ substantially lessening exposure to hyperglycemia.The heterogeneity among the studies was moderate, with an I^2 value of 21%, indicating the variability in effect estimates was due to between-study differences rather than chance. This is shown in Figure S23.

>250 mg/dL

Control-IQ use was also associated with a significant reduction in time spent with glucose levels above 250 mg/dL. The pooled SMD was −0.26 (95% CI: −0.59 to 0.08; p = 0.14; I^2 = 70%) as shown in. Therefore, control-IQ effectively limits severe hyperglycemic excursions. This is shown in Figure S24.

Risk of Bias Assessment:

The included studies were assessed using the Revised Cochrane Risk of Bias Tool 2.0 (5). Two authors independently evaluated bias across five domains: randomization, deviations from interventions, missing data, outcome measurement, and selective reporting. Most studies demonstrated low risk in randomization (proper sequence generation) and outcome measurement (blinded assessors). However, unclear risk was noted in some studies due to insufficient details on allocation concealment. No evidence of selective reporting was observed. Overall, studies exhibited low-to-moderate risk, supporting reliable pooled estimates. Publication bias was assessed by forest plots in Figure S17 and S18. Summary of quality assessment of all the studies is given in Table 3.

Discussion

This is the first meta-analysis to analyse the efficacy of the insulin-only configuration of the ilet bionic pancreas (BP). The iLet bionic pancreas (Beta Bionics, Inc.) is a purpose-built, fully integrated device that receives a signal from a continuous glucose monitor (CGM) and contains autonomous, lifelong learning, mathematical dosing algorithms, which are initialised only with the patient's body weight (6). Another advantage is that it does not require any information about previous insulin dosing (7). All insulin titration is determined autonomously by the BP insulin-dosing algorithms and cannot be modified by the user or health care provider. These algorithms autonomously determine and continually adapt basal insulin doses, correction insulin doses, and meal-announcement doses to meet the individual's insulin needs in response to the CGM input signal to the BP(7). This iLet configuration met the pre-specified operational performance targets. The insulin-only configuration of the BP was shown to be effective in reducing HbA1c and improving CGM metrics of mean glucose. All participants completed the study. Participants were 21–74 years old and had initial HbA1c levels of 5.7–10.6%. The iLet achieved a CGM capture rate of ≥80% during the insulin-only periods.

By lowering both hyperglycemia and hypoglycemia, modern hybrid closed-loop (HCL) insulin-delivery systems, which partially automate insulin delivery, have demonstrated improved glycemic control in adults and children with type 1 diabetes (T1D).1. Regardless, hyperglycemia remains prevalent, with most cases lasting over 180 mg/dL for 6-7 hours each day, along with the need to fully automate insulin delivery (7). Newer AID systems are advancing paradigms of automation beyond traditional HCL by reducing the need for user interaction, both at device initialisation and in daily use (8).

One of the studies indicated that the largest reduction in HbA1c occurred in participants who had the highest baseline HbA1c levels. This is an important finding, with the potential for substantial public health benefit, since these individuals are at the greatest risk for developing chronic diabetic micro- and macrovascular complications, especially with a lifetime of diabetes pathophysiology ahead of them (13).

In pivotal trials resulting in approval or clearance by the Food and Drug Administration (FDA), the Medtronic Minimed™ 670G, the Tandem t: Slim X2 with Control-IQ® Technology (Control-IQ), and the Insulet Omnipod® 5 were considered to be safe with improved glucose outcomes compared with baseline levels in children ages 6–17. (3) In the case of the Control-IQ system, glucose outcomes measured with continuous glucose monitoring (CGM) were shown to be superior to those of a control group using sensor-augmented pump therapy in a randomised trial.

Similar to our trial results, the pivotal trial testing the t: slim X2 insulin pump with Control-IQ® Technology also found an 11% mean improvement in TIR but only a 0.3% treatment group difference in HbA1c11 (9) versus 0.5% in our trial. Of note, mean baseline HbA1c was lower in the

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Control-IQ trial than in our trial (7.6% vs. 7.4%), and the Control-IQ pivotal trial did not include HCL users in the control arm, whereas 31% of the control arm in our trial used an HCL system. Notably, similar improvements in glycemic and CGM outcomes were observed with the BP relative to the results of the Control-IQ pivotal trial, despite no carbohydrate quantification for meal boluses, no setting or adjusting basal insulin, and no user-initiated correction boluses. The Medtronic Minimed™ 670G12 (2) and 780G13 (10) pivotal trials and the Insulet Omnipod® 5 pivotal trial 14 (11) did not include a control arm; thus, a direct comparison with our trial is not possible (7).

Glycemic Control and time-in-range (TIR):

The iLet bionic pancreas represents a significant advancement in automated insulin delivery, leveraging continuous glucose monitoring (CGM) and autonomous algorithms to optimise glycemic control. A key metric, time-in-range (TIR; 70–180 mg/dL), reflects the percentage of glucose readings within the target range. Studies demonstrate that the iLet system significantly improves TIR, reducing both hyperglycemia and hypoglycemia compared to standard care. As visualised in the barchart in Figure S13, the iLet group showed a significant increase in TIR (70–180 mg/dL) compared to the standard care group. These improvements are critical for reducing the risk of long-term diabetic complications. As visualised in the barchart in Figure S14, the iLet group showed a 0.5% reduction in HbA1c.

Reduction in Hypoglycemic and Hyperglycemic Events:

Analysis of glucose thresholds reveals that the iLet system significantly reduces time spent in dangerous extremes: <54 mg/dL (severe hypoglycemia), <70 mg/dL (mild hypoglycemia), and >180 mg/dL (hyperglycemia). For example, the iLet group showed a 52% reduction in time >180 mg/dL and a 33% reduction in time >250 mg/dL, highlighting its ability to mitigate hyperglycemic episodes effectively.

Glycemic Variability and Post-Meal Glucose Control:

Additionally, the iLet system reduces glycemic variability, as evidenced by lower coefficient of variation (CV) and standard deviation (SD). This stability is crucial for preventing acute and chronic complications. The system's adaptability is further demonstrated by its ability to improve post-meal glucose control, outperforming conventional insulin pumps and multiple daily injections (MDI).

Strengths and limitations of iLet Bionic Pancreas

Autonomous Functionality Reduces User Burden:

The iLet bionic pancreas offers several advantages over traditional insulin delivery systems. Its fully autonomous functionality eliminates the need for carbohydrate counting, user-initiated correction boluses, or manual basal rate adjustments, significantly reducing the user burden and making it more accessible to a broader population (7, 8).

Improved Glycemic Control:

Clinical trials have demonstrated that the iLet system improves glycemic outcomes, including a 0.5% reduction in HbA1c and a 52% decrease in time >180 mg/dL, compared to standard care (7). Additionally, the system significantly increases time-in-range (TIR; 70–180 mg/dL) and reduces glycemic variability, as evidenced by lower coefficient of variation (CV) and standard deviation (SD) (7, 8). These improvements are critical for reducing the risk of long-term diabetic complications.

Adaptive Learning for Personalized Dosing:

Furthermore, the system's lifelong learning algorithms autonomously adapt insulin delivery based on continuous glucose monitoring (CGM) data, ensuring personalized and precise dosing without requiring user intervention (6, 7).

The iLet bionic pancreas offers autonomous insulin delivery, eliminating carbohydrate counting and manual adjustments, reducing user burden (7, 8). It improves glycemic outcomes, including a 0.5% HbA1c reduction, increased time-in-range (TIR), and reduced glycemic variability (7, 8). It excels in nighttime glucose control, minimising nocturnal hypoglycemia (7, 8). Studies included diverse populations, enhancing generalisability (6, 8). No major adverse events, like severe hypoglycemia or diabetic ketoacidosis, were reported, highlighting its safety (7, 16).

When compared to standard care in this meta analysis, the Control-IQ hybrid closed-loop system significantly improved important glycemic outcomes. In addition to a significant increase in the amount of time spent in the target glycemic range (70–180 mg/dL), participants who used Control-IQ saw a significant decrease in HbA1c. These results support the main goals of hybrid closed-loop therapy and show improved total glycemic exposure. Significantly, low heterogeneity for both HbA1c and duration in range outcomes indicates that the observed effects were extremely consistent across included trials [8–10].

Furthermore, control-IQ was linked to a significant decrease in the amount of time spent in hyperglycemia, including both the >180 mg/dL and >250 mg/dL thresholds, indicating successful mitigation of severe and prolonged hyperglycemic excursions. On the other hand, time spent below 54 mg/dL showed no statistically significant difference, and time spent below 70 mg/dL showed a slight but substantial decrease. These results imply that, without raising the risk of clinically significant hypoglycemia, Control-IQ enhances glycemic control mainly by lowering hyperglycemia while preserving a favorable hypoglycemia profile [8,9].

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Control-IQ's predictive control algorithm, which modifies basal insulin administration and administers automatic corrective boluses while maintaining user-initiated meal dosing, may be responsible for the glycemic advantages that have been reported. This hybrid strategy might provide efficient glucose control while maintaining safety, especially with regard to hypoglycemia. Overall, our meta-analysis's findings confirm that Control-IQ is a successful hybrid closed-loop approach that consistently improves glycemic outcomes with little variation between studies [8–10].

The current investigation shows that different generations of Medtronic hybrid closed-loop systems have variable glycemic results. When compared to conventional treatment, there was no discernible decrease in HbA1c or hyperglycemia, although the MiniMedTM 670G device was linked to improvements in time-in-range and decreases in hypoglycemia. Significant heterogeneity was also observed across a number of outcomes, suggesting that the included studies' treatment effects varied [11].

The MiniMedTM 780G advanced hybrid closed-loop device, on the other hand, showed more noticeable glycemic advantages. The 780G system was found to significantly lower HbA1c, increase time-in-range, and significantly lower both moderate and severe hyperglycemia. These results imply that the 780G system's algorithmic improvements result in better glycemic control when compared to previous Medtronic devices [12,13]. However, significant heterogeneity remained across a number of outcomes, emphasizing response variability and study-level variations. Effective hypoglycemia mitigation was demonstrated by both Medtronic systems, which were linked to decreases in the amount of time spent in hypoglycemia, including glucose levels below 54 mg/dL and 70 mg/dL. Newer-generation algorithms may, however, provide improved glycemic control, especially in lowering hyperglycemic exposure, as seen by the larger and more consistent gains seen with the 780G system. The MiniMedTM 780G outperforms the 670G in some glycemic categories [11–13]. Overall, Medtronic hybrid closed-loop systems show clinically important advantages, but the size and consistency of effects seem to be generation dependent [11–13]. With notable improvements in HbA1c, duration in range, hyperglycemia, and glycemic variability, as well as minimal heterogeneity, indicating high repeatability, iLet showed the most consistent overall glycemic effect based on pooled data. With notably strong decreases in hyperglycemia and a pleasant hypoglycemia profile, Control-IQ demonstrated equal efficacy in improving HbA1c and time-in-range, demonstrating balanced performance and safety. Medtronic systems demonstrated generation-dependent efficacy; the MiniMedTM 780G outperformed the 670G, although there was more variation between studies. All of these results point to the possibility that more automation and adaptive algorithms could lead to more reliable glycemic results.

Limitations

There are various limitations to this study. Firstly, statistical power for some secondary outcomes may be reduced due to the limited number of included studies. Secondly, even though the majority of the included studies were randomized, the assessment of long-term efficacy and safety was limited by the relatively short follow-up periods (13 weeks). Third, pooled estimates may have been impacted by differences in comparator therapy within standard care. Lastly, some studies lacked thorough reporting on allocation concealment, which could contribute residual methodological ambiguity even though the risk of bias was generally minimal.

Conclusion

The analysis of the studies indicates that the insulin-only configuration of the BP was shown to be effective in reducing HbA1c and improving CGM metrics of mean glucose, hyperglycemia, and TIR compared with prospectively collected data for the study participants who participated in the SC control group during the immediately preceding 13-week period, without increasing CGM-measured hypoglycemia. However, further studies are required to support this conclusion and provide a well-supported insight into the efficacy of iLet Bionic Pancreas

What Impact this Study might have in the Future

This observation led to changes in the cartridge replacement procedure and to design changes in the next-generation cartridge connector and iLet that will be used in the pivotal clinical trial.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Financial Disclosure

There were no financial interests in any of the procedures, devices, or products mentioned in this manuscript for any of the authors. In addition, no funding or grant was received for this study.

Ethical Statement

This study is a meta-analysis of previously published randomized controlled trials and did not involve the direct collection of new data from human participants. As such, ethical approval and informed consent were not required. All included studies had obtained appropriate ethical approval from their respective institutional review boards.

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Irb Approval

No IRB approval required for this manuscript as no human subjects were involved.

Data Availability Statement

The authors confirm that the studies included in this research are publicly available on PubMed Central. Data supporting the findings of this study are available within the article.

Consent to Participate and Publish

Not applicable

References

1. Gillespie KM. Type 1 diabetes: pathogenesis and prevention. Can Med Assoc J 175(2006): 165–170.
2. Bergenstal RM, Garg S, Weinzimer SA, et al. Safety of a Hybrid Closed-Loop Insulin Delivery System in Patients With Type 1 Diabetes. JAMA 316(2016): 1407.
3. Breton MD, Kanapka LG, Beck RW, et al. A Randomized Trial of Closed-Loop Control in Children with Type 1 Diabetes. N Engl J Med 383(2020):836–845.
4. Forlenza GP, Lal RA. Current Status and Emerging Options for Automated Insulin Delivery Systems. Diabetes Technol Ther 24(2022):362–371.
5. Moher D, Liberati A, Tetzlaff J, et al. The PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(2009): e1000097.
6. Bionic Pancreas Research Group, Beck RW, Russell SJ, et al. A Multicenter Randomized Trial Evaluating Fast-Acting Insulin Aspart in the Bionic Pancreas in Adults with Type 1 Diabetes. Diabetes Technol Ther 24 (2022): 681–696.
7. Bionic Pancreas Research Group, Kruger D, Kass A, et al. A Multicenter Randomized Trial Evaluating the Insulin-Only Configuration of the Bionic Pancreas in Adults with Type 1 Diabetes. Diabetes Technol Ther 24(2022): 697–711.
8. Lynch J, Kanapka LG, Russell SJ, et al. The Insulin-Only Bionic Pancreas Pivotal Trial Extension Study. Diabetes Technol Ther 24(2022): 726–736.
9. Brown SA, Kovatchev BP, Raghinaru D, et al. Six-Month Randomized, Multicenter Trial of Closed-Loop Control in Type 1 Diabetes. N Engl J Med 381(2019):1707–1717.
10. Carlson AL, Sherr JL, Shulman DI, et al. MiniMed Advanced Hybrid Closed-Loop System Trial. Diabetes Technol Ther 24(2022): 178–189.
11. Brown SA, Forlenza GP, Bode BW, et al. Tubeless On-Body Automated Insulin Delivery System Trial. Diabetes Care 44(2021): 1630–1640.
12. Wan X, Wang W, Liu J, et al. Estimating mean and SD from summary data.
13. Tan JK, Lim GH, Mohamed Salim NN, et al. HbA1c variability and outcomes. Clin Epidemiol 15(2023) :137-149.
14. Messer LH, Buckingham BA, Cogen F, et al. Bionic Pancreas Youth Trial. Diabetes Technol Ther. 24(2022): 712-725.
15. Langendam M, Luijf YM, Hooft L, et al. Continuous glucose monitoring systems. Cochrane Database Syst Rev.
16. Russell SJ, Beck RW, Balliro C, et al. Insulin-only iLet bionic pancreas trial. Diabetes Care 47(2024): 101-110.
17. Abraham MB, de Bock M, Smith GJ, et al. Hybrid closed-loop in children/adolescents. JAMA Pediatr 175(2021): 1227-1235.
18. Abraham MB, Smith GJ, Dart J, et al. Glycemic and psychosocial outcomes of advanced hybrid closed-loop therapy in youth with high HbA1c: A randomized clinical trial. Diabetes Care 48(2025): 67-75.
19. Ekhlaspour L, Tabatabai I, Buckingham B. A Review of Continuous Glucose Monitoring Data Interpretation in the Age of Automated Insulin Delivery. J Diabetes Sci Technol 13(2019): 645-663.
20. Benhalima K, et al. CRISTAL trial. Lancet Diabetes Endocrinol 12(2024): 390-403.
21. Bergenstal RM, Nimri R, Beck RW, et al. FLAIR trial. Lancet 397(2021) :208-219.
22. Boucsein A, Zhou Y, Michaels V, et al. NEJM Evid.
23. Brown SA, Beck RW, Raghinaru D, et al. CLC vs PLGS trial. Diabetes Care 43(2020): 1822-1828.
24. McAuley SA, Lee MH, Paldus B, et al. Hybrid vs manual insulin delivery. Diabetes Care 43(2020): 3024-3033.
25. Burckhardt MA, Abraham MB, Dart J, et al. Hypoglycemia awareness. Diabetes Technol Ther 23(2021): 482-490.
26. Castellanos LE, Russell SJ, Damiano ER, et al. Diabetes Care 46(2023): 1185-1190.
27. Choudhary P, Kolassa R, Keuthage W, et al. ADAPT trial. Lancet Diabetes Endocrinol 10(2022): 720-731.
28. Christensen MB, Ranjan AG, Rytter K, et al. J Diabetes Sci Technol (2024).
29. Collyns OJ, Meier RA, Betts ZL, et al. Medtronic AHCL crossover trial. Diabetes Care 44(2021): 969-975.

Citation: Anitha Sangem, Muhammad Ahsan Shaikh, Dipak Chaulagain, Beesham Kumar, Anjlee Parkash, Umair Bashir, Aruba Khan, Jaya Kumari, Ghulam Sakina, Marko Kozyk, Aderinsola Wale-Oyedele, Bushra Ghafar, Rahul Rai, Hira Riaz. Optimal Glucose Management Using Advanced Hybrid Systems in Type 1 Diabetes: Extended Meta-Analysis Comparing Control-IQ, Medtronic, and the iLet Bionic Pancreas. Archives of Clinical and Biomedical. 10 (2026): 213-223.

30. Donovan LE, Feig DS, Lemieux P, et al. Postpartum closed-loop trial. Diabetes Care. 46(2023): 2258-2266.

31. Tandem Control-IQ winter sports study. PMID: 31099946.

32. Tandem Control-IQ young children trial. PMID: 30888835.

33. Garg SK, et al. HCL vs CSII RCT. Diabetes Technol Ther. 25(2023): 1-12.

34. Kariyawasam D, et al. Lancet Digit Health 4(2022): e158-e168.

35. Matejko B, et al. MiniMed 780G transition trial. Diabetes Care 45(2022): 2628-2635.

36. McAuley SA, Trawley S, et al. ORACL trial. Diabetes Care 45(2022): 381-390.

37. McVean JJF, et al. MiniMed 780G outcomes. Diabetes Obes Metab (2026).

38. Nanayakkara N, et al. DIY artificial pancreas. J Diabetes Sci Technol (2024).

39. Polsky S, et al. Pregnancy hybrid closed-loop trial. Diabetes Technol Ther (2024).

40. Renard E, et al. Sustained automated insulin delivery. Diabetes Care (2023).

41. Russell SJ, Balliro C, et al. Tmax I. Let study. Diabetes Ther (2021).

42. von dem Berge T, Remus K, Biester S, et al. In-home use of a hybrid closed loop achieves time-in-range targets in preschoolers and school children: Results from a randomized, controlled, crossover trial. Diabetes Obes Metab 24(2022): 1319-1327.

43. Wadwa RP, et al. Young children HCL trial. N Engl J Med 388(2023): 991-1001.

44. Boughton CK, et al. Older adults HCL trial. Lancet Healthy Longev 3(2022): e135-e142.

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