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A Review on Hybrid Closed Loop Insulin Delivery System

S.G.Kuralarasan

Krishna Teja Pharmacy Collage ,India

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ABSTRACT

Type 1 diabetes mellitus (T1DM) is a habitual autoimmune condition taking lifelong insulin remedy. Conventional approaches like multiple quotidian injections or continuous subcutaneous insulin infusion are limited by hypoglycaemia trouble, glycaemic variability, and patientburden. Automated insulin delivery (AID) systems, particularly crossbred unrestricted- circle (HCL) systems, integrate continuous glucose monitoring, insulin pumps, and control algorithms to optimize insulin delivery. HCL systems automate rudimentary insulin and correction boluses, taking manual mess boluses, and haves hown significant benefits, including increased time- in- range (TIR), lower HbA1c, reduced hypoglycaemia, and enhanced quality of life. These benefits are seen across different populations, including children, grown- ups, and pregnant women. Despite these advancements, limitations remain, analogous as mess gelcap dependence, delayed post- mess glucose control, sensor delicacy issues, cost, and specialized malfunctions. fully unrestricted- circle systems are being developed to count manual input and further mimic physiological insulin regulation. With ongoing advances,HCL systems represent a significant step toward a fully independent artificial pancreas, offering bettered glycaemic control, safety, and quality of life for individualities with T1DM. These systems have the eventuality to revise diabetes operation and meliorate patientissues.

INTRODUCTION

Diabetes is ahabitual complaint characterizedby high bloodsugar situations, performingfrom the body's incapability to produce or effectively use insulin. This can lead to colourful health complicationsovertimeifnotmanagedduly. Thetwomaintypesofdiabetesare Type1,where the body produces little to no insulin, and Type 2, where the body does not use insulin well.

Type 1 diabetes mellitus (T1DM) is a habitual autoimmune complaint characterized by the destruction of insulin-producing β- cells in the pancreas, leading to insulin insufficiency. This autoimmune process is told by both inheritable vulnerability and environmental triggers. The inheritable predilection to T1DM is substantially associated with the HLA gene complex located on the short arm of chromosome 6 (6p21), especially the HLA- DRB1, HLA-DQA1, and HLADQB1 class II loci. These alleles have been explosively linked to the threat of developing T1DM. also, genome wide association studies have linked several other non-HLA regions associated with complaint development.

*Corresponding author. S.G Kuralarasan
E-mail address: sgkuralarasan2005@gmail.com

Regulatory T cells (Tregs) play an important part in maintaining vulnerable forbearance and precluding autoimmune responses. still, in individualities with T1DM, the mechanisms that lead to the loss of vulnerable control by these cells remain unclear despite expansive exploration.

Presently, the operation of T1DM requires lifelong parenteral insulin administration, which is frequently physically and psychologically demanding. Indeed, with precise insulin remedy, cases remain at threat for long-term complications, similar as cardiovascular complaint, neuropathy, and retinopathy. As a result, there's a nonstop hunt for indispensable treatments and preventative strategies to reduce the complaint burden.

Multiple transnational exploration programs have been conducted to identify threat pointers for T1DM, fastening on both inheritable and environmental factors. Among the most significant biomarkers are autoantibodies directed against β- cell antigens. These include insulin, glutamic acid decarboxylase (GAD), IA- 2, and ZnT8. The presence of these autoantibodies reflects ongoing vulnerable exertion against pancreatic cells.still,it'simportant to note that a subset of cases may develop T1DM without sensible autoantibodies.

The development of T1DM generally progresses through several phases:

1. Inheritable vulnerability phase linked through inheritable testing. Tools like the inheritable threat Score (GRS) are now used to assess an existent's predilection and companion preventativeinterventions.

2. Inauguration of autoimmunity touched off by environmental factors similar as viral infections, diet, or poisons. This phase is marked by the appearance of autoantibodies against β- cellantigens.

3. Progressive β- cell destruction leads to significant insulin insufficiency. Clinical symptoms of diabetes generally appear when about 90 of the β- cells aredestroyed.

Challenges of Conventional Insulin Therapy in Type 1 Diabetes Mellitus

Type 1 Diabetes Mellitus (T1DM) is an autoimmune disorder characterized by the destruction of pancreatic beta cells, leading to absolute insulin deficiency. As a result, lifelong insulin therapy is required. Conventional insulin therapy typically involves multiple daily injections (MDI) or continuous subcutaneous insulin infusion (CSII). Despite being the cornerstone of treatment, conventional insulin therapy presents several significant challenges that impact glycaemic control and patient quality oflife.

One of the foremost challenges is achieving tight glycaemic control without causing hypoglycaemia. Intensive insulin therapy aims for glycated haemoglobin (HbA1c) levels below7%,Asrecommendedbyguidelines. However,maintainingthistargetisdifficultbecause of individual variations in insulin sensitivity, meal patterns, physical activity, and stress. Consequently, patients may experience wide fluctuations in blood glucose, increasing the risk of both hyperglycaemia andhypoglycaemia.

Hypoglycaemia, particularly nocturnal episodes, Is a major limitation of conventional insulin regimens. Older basal insulins like neutral protamine Hagedorn (NPH) have unpredictable pharmacokineticsandahigherriskofcausing lowbloodsugarlevelsduringthenight.Though newer basal insulin analogues like glargine, detemir, and Gla-300 offer more stable profiles, challenges remain in fully eliminating hypoglycaemia risk, especially in patients with hypoglycaemia unawareness.

Patient adherence and education are other crucial hurdles. Conventional insulin therapy demands complex decision-making involving carbohydrate counting, insulin-to-carb ratio calculations,frequentglucose monitoring,andadjustmentsbasedonexerciseandillness.This places a heavy cognitive and emotional burden on patients, making it difficult to sustain optimal therapy over the long term without extensive education andsupport.

The dawn phenomenon, a natural rise in early morning blood glucose due to hormonal surges (e.g., growth hormone and cortisol), further complicates therapy. It often requires dose timing adjustments or switching to CSII, which is not always accessible or affordable, especially in low-resource settings.

Moreover, conventional insulin therapy can lead to weight gain, which is undesirable, particularly in patients already struggling with metabolic imbalance. The insulin itself, especially when given in excessive amounts to prevent hyperglycaemia, may promote fat storage.

Technological limitations and accessibility also hinder effective therapy. Although continuous glucose monitoring (CGM) and insulin pumps (CSII) have demonstrated better glycaemic outcomes and reduced hypoglycaemia, they remain expensive and less accessible in many countries. Thus, most patients rely on MDI with basal and bolus analogues, which still fall short of mimicking physiologic insulin secretion precisely.

Inconclusion, while conventiona linsulint herapyremain sthemainstay of T1DM management, it isf raught with challengessuch ashypoglycaemia, glycaemicvariability, dawn phenomenon, patient adherence issues, and accessibility limitations. Innovations like hybridclosed-loop systems and smart insulin are emerging to address these issues, but until they are widely available and affordable, optimizing current insulin strategies and patient education remains critical. Tight glucose control refers to the careful regulation of blood sugar levels to maintain them with in a specific target range. This approach is vital for minimizing long-term complications in individuals with diabetes and for optimizing outcomes in critically ill patients. By reducing the risks of both hyperglycaemia (high blood sugar) and hypoglycaemia (low blood sugar), tight glucose control plays a key role in effective diabetes and critical care management.

AUTOMATED INSULIN DELIVERY

Automated insulin delivery lately, automated insulin delivery (AID) systems, also appertained to as artificial pancreas or unrestricted-circle glucose control systems,have surfaced as a major advancement in diabetes operation. These systems are designed to automatically and safely regulate blood glucose situations with minimum case intervention. They serve through the integration of three crucial factors a subcutaneous insulin infusion pump, a subcutaneous nonstop glucose monitor (CGM), and a sophisticated control algorithm that continuously calculates the needed insulin lozenge grounded on real- time glucosereadings.

Thesubcutaneous route is preferred for bothglucose monitoring and insulin deliveryduetoits safety, practicality, and felicity for inpatient and home use. In discrepancy, intravenous (IV) delivery can lead to complications such as catheter dislodgement, migration, or blockage due tofibrinclots.Theintraperitoneal(IP) route,whileeffective,requiressurgicalimplantationand may stimulate the product of anti-insulin antibodies, potentially compromising remedy effectiveness and addingpitfalls.

AID systems are capable of delivering insulin in highly precise micro -doses,whichareadjusted continuously grounded on CGM data. This enables the system to maintain blood glucose situations within a asked range and reduce the prevalence of both hyperglycaemia and hypoglycaemia. To further enhance glycaemic control and safety, experimenters have also explored incorporating fresh hormones similar as glucagon and amylin analogues into AID systems. Overall, AID systems represent a transformative step toward completely automated diabetescare, offering bettered glycaemic control, lesser convenience, and enhanced qualityof life for individualities living with diabetes.

TYPES OF AUTOMATED INSULIN DELIVERY SYSTEMS

There are two types of Automated Insulin DeliverySystems:

1. Fully Closed Loop Insulin DeliverySystem.
2. Hybrid Closed Loop Insulin DeliverySystem.

FULLY CLOSED LOOP INSULIN DELIVERY SYSTEM

A fully closed-loop insulin delivery system, often referred to as an artificial pancreas, autonomously adjusts insulin administration based on real-time glucose monitoring. It eliminates the need for user intervention, such as carbohydrate counting or manual bolus injections.By continuously tracking glucose levels and utilizing a control algorithm, the system dynamically regulates insulin delivery, closely replicating the natural function of a healthy pancreas. Fully automated insulin delivery systems are still in development and undergoing clinical trials, showing promising outcomes in both inpatient and outpatient settings.

HYBRID CLOSED LOOP INSULIN DELIVERY SYSTEM

A hybrid closed-loop drug delivery system, also known as an artificial pancreas, is a medical device that automates insulin delivery for people with type1diabetes. It combines a con tinuous glucose monitor (CGM) with an insulin pump, using a control algorithm to adjust insulin delivery based on real-time glucose levels. This system helps manage blood glucose levels more effectively and improve the overall quality of life for individuals with type 1 diabetes. It is referred toas "hybrid" because it still requires user input for mealtime insulinboluses.

Evolution and Development of Hybrid Closed-Loop Insulin Delivery Systems:

The idea of unrestricted-circle glucose control, also known as an artificial pancreas, has been discussed in diabetes research since the 1960s.

However, due to limited technology, it remained mostly theoretical for many years. The feasibilityofcreatingapractic alandwearableunrestricted-circlesystembecamerealisticwith important technological advances.These included smaller and morereliable insu lin pumps,the development of continuous glucose monitoring (CGM) systems with high accuracy, and the availability of secure wireless communication technologies. Together, these innovations laid the groundwork for real-time, automated insulin delivery systems.

Early versions of unrestricted-circle systems were basic and mainly aimed at reducing the risk of hypoglycaemia. The first commercialsystems include dalowglucose suspend (LGS)feature that automatically stopped insulin delivery when glucose levels dropped below a certain level. This helped reduce the severity and frequency of hypoglycaemic episodes. As these systems improved, predictive low glucose suspend (PLGS) technology was introduced. These systems predicted hypoglycaemia and paused insulin delivery before it happened. While both LGSand PLGS were important milestones in unrestricted-circle technology, they focused only on preventing hypoglycaemia and did not addresshyperglycaemia.

Two widely used PLGS systems are the MiniMed 640G insulin pump with SmartGuard technology (Medtronic, Northridge, CA, USA) and the t-Slim X2 insulin pump with SmartGuard technology (Tandem Diabetes Care, San Diego, CA, USA). These systems have become an important part of standard diabetes care in several countries, offering significant benefits for people with Type 1 Diabetes Mellitus (T1DM).

Following these developments, researchers started working on more advanced systems aimed at achieving full automation in insulin delivery. This led to the creation of predictive hyperglycaemia and hypoglycaemia minimization (PPHM) systems. These systems retained PLGS features but also included automatic correction doses when the CGM predicted glucose levels would go above a certain threshold. Still, these systems did not provide continuous insulinmodulation.Despitethislimitation,theyhelpedimprovetime-in-range(TIR)forblood glucose levels, especially during the night, without increasing the risk of hypoglycaemia in both children andadults.

Later innovations focused on developing more advanced algorithms that could continuously and automatically adjust insulin delivery based on CGM data. Initial safety and feasibility studies were conducted in inpatient clinical settings, followed by structured trials in diabetes camps and inpatient studies.Thesetrials showed significant progres sinkeeping glu coselevels within the target range and reducing both hypo- and hyperglycaemic episodes.

However, achieving 24-hour unrestricted-circle control remained challenging, especially during daily activities like eating and exercising. Post-mealglucose control is difficult be cause of delays in the action of subcutaneous insulin and the variable absorption rates of carbohydrates. These factors make completely automated systems, which do not require user input during meals, prone to postprandial hyperglycaemia and later hypoglycaemia.

As a result, hybrid unrestricted-circle (HCL)systems were introduced. These systems au tomate basic insulin delivery and correction doses but still allow users to manually admin ister boluses during meals. HCL systems offer a balance between safety and automation and have proven effective in-home settings across a wide range of patient populations, including children, adolescents, adults, and pregnantwomen. The Medtronic MiniMed 670G was the first commercially available HCL system, introduced in 2016. Since then, newer systems like the Tandem Control-IQ and the CamAPS FX closed- loop app (CamDiab Ltd., Cambridge, UK) have received regulatory approval and entered the market. Many other HCL systems are currently in development or awaiting approval, promising further improvements in the management of T1DM.

ADVANTAGES

A. Reduced Hypoglycemia: Demostrated a reduction in hypoglycemia events, especially during night time, with the use of HCLSystems.

B. Improved Quality of life: Reported reduced diabetes-related distress & improved quality of life among HCL systemusers.

C. Improved Glycemic Control and Time in Range (TIR): Found that HCL systems significantly improved HbA1c & increased time-in-range compared to Sensor- augment ed pumps.

D. Meta-Analysis of Efficacy & Safety: Systematic review showing that artificial pancreas systems (including HCL) improve glycemic control & reducehypoglycemia.

E. Better Overnight Glucose Control: Thisstudy found significantly more times pentin range overnight with HCL Systems, reducing nocturnal hypoglycemia & glucose variability.

F. Reduction in Glucose Variability: Demonstrated decreased glucose variability, especially in patients prone to hypoglycemia, using sensor-driven automated insulin adjustmentsystems.

G. Reduced Diabetes management Burden (Less manual Decision-making): Participants reported less time spent on diabetes management decisions, reducedstress & more confidence in glucosecontrol.

H. Safety & Feasibility in young children: Demonstrated safety & effectiveness of the HCL system in children under 14, expanding use to younger agegroups.

I. Support for physical Activities: HCL systems effectively adjusted insulin delivery during & after exercise, reducing the risk of exercise-inducedhypoglycemia.

LIMITATIONS

A. Meal Bolus still required (not fully automated): Noted that while the system automates basalinsulin, usersmustmanually enter carbohydrate intake & bolus insulin for meals.

B. User Burden (Alarms, Calibrations, ManualInput): Found that upto 30% of youth discontinued HCL use within 6 months, citing alarm fatigue, frequent calibration & complex interface.

C. Delayed Insulin Action Limits Post-Meal Control: Showed that insulin-only HCL systems struggle with postprandial spikes due to the slow onset of subcutaneous insulin action.

D. Cost & Accessibility: HCL systems are expensive & not universally accessible, especially in low-income or public healthcare settings.

E. Technology Issues: Sensor failures & connectivity problems: Technical failures such as sensor errors, Bluetooth drops, & auto-mode exits, affecting patient trust in the system.

F. Algorithm Limitations (Delayed Response to Highs / Lows): While HCL systems are generally effective, the algorithms used can sometimes be slow in reacting to rapid changes in blood glucose, leading to temporary periods of high or low glucose levels before the systemadjusts.

G. Need for frequent calibration & Sensor : Even though HCL systems utilize continuous glucose monitoring (CGM), they still require periodic sensor calibrations (especially with some systems), & sensor accuracy can vary, affecting the system's overall performance.

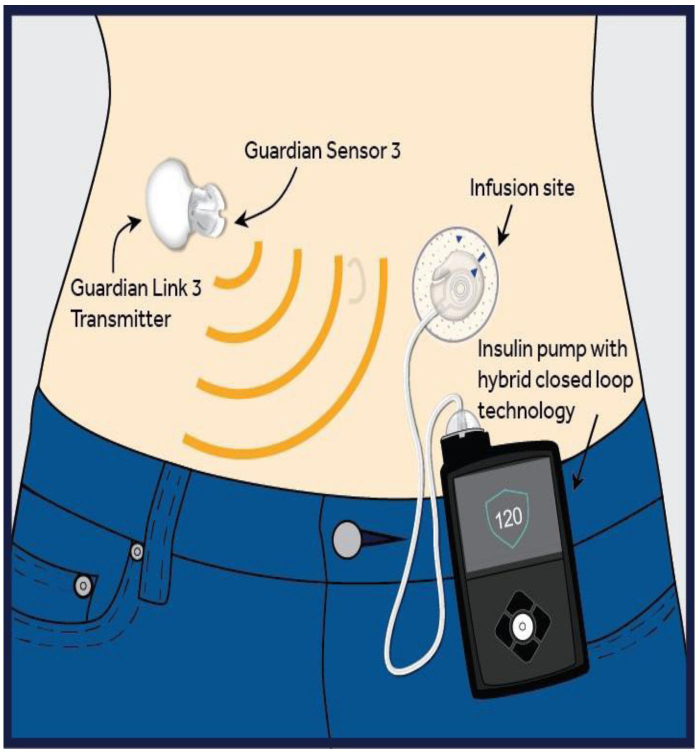

FIG. 1: Arrangement of Hybrid Closed Loop System

SYSTEM COMPONENTS:

1. Continuous Glucose Monitor (CGM)
2. Insulin Pump
3. Control Algorithm

CONTINUOUS GLUCOSE MONITOR (CGM)

A continuous glucose monitor (CGM) is a device that helps people with diabetes track their blood sugar situations all day and night. CGM systems are wearable bias that automatically and continuously measure glucose situations in the interstitial fluid, which is the fluid just under the skin. The glucose situations in this fluid are nearly related to blood glucose situations and are generally stable, not affected important by changes in pH or impurity.

CGM detectors are generally worn on the upper arm or the tummy and can stay in place for over to two weeks, depending on the system. Some advanced models have detectors that are implanted under the skin, allowing for glucose monitoring for over to 180 days. The data from the detector is transferred to an external device, similar as a handheld device or a smartphone. numerous CGM systems come with automated cautions that notify druggies when their glucose situations are too high or too low. By tracking glucose trends over time, CGM systems give druggies a complete picture of their glucose patterns, helping them manage diabetes more effectively and proactively.

A standard CGM system includes three main corridor a detector, a transmitter, and a receiver. The detector is placed under the skin and continuously checks glucose situations. It sends the data to a transmitter, which is attached to the skin above the detector. The transmitter also sends the glucose readings wirelessly to a receiver, either a devoted device or a smartphone or smartwatch through an app.

Presently available CGM systems are divided into two types real- time CGM and intermittently scrutinized(is) CGM. rtCGM provides nonstop, real-time (rt) glucose readings along with prophetic cautions, while isCGM only shows glucose data when the stoner manually scans the transmitter with a compatible device or smartphone.

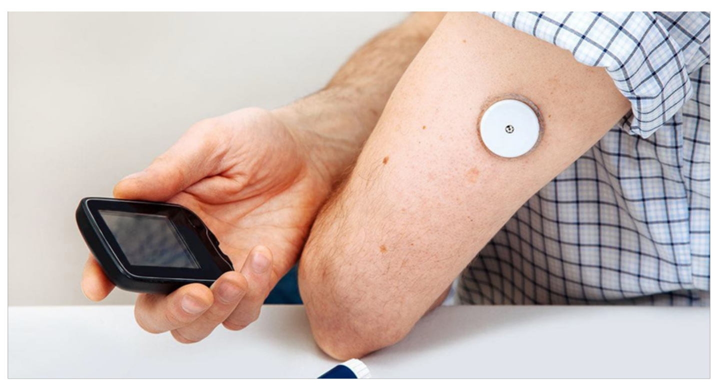

FIG. 2: A Continuous Glucose Monitor (CGM) placed at the upper arm

INSULIN PUMP

Insulin pump therapy is increasingly recommended to achieve and maintain optimal glycaemic control in individuals with type 1 diabetes mellitus. Since its introduction in the 1970s, this approach has gained significant attention as a major advancement in diabetes management. Compared to conventional or multiple daily injection (MDI) regimens—

commonly known as the basal-bolus approach—insulin pump therapy offers several advantages. These include greater patient satisfaction, a more flexible lifestyle, improved glycaemic control, reduced frequency of hypoglycaemic episodes, decreased HbA1c levels and glycaemic variability, and a lower risk of long-term complications such as diabetic retinopathy and nephropathy.

While the metabolic benefits of insulin pump therapy have been extensively documented, aspects such as quality of life and patient satisfaction remain under explored, with relatively few studies addressing these outcomes. Furthermore, there is a notable lack of data regarding the effectiveness of insulin pump therapy in the Moroccan population. In Morocco, access to insulin pump therapy remains limited due to high upfront and ongoing costs, lack of insurance coverage or reimbursement, and general unavailability. As a result, only a small number of patients are currently treated with insulin pumps. Despite these challenges, our study represents the first and largest monocentric investigation in Morocco evaluating the impact of insulin pump therapy on glycaemic control and patient satisfaction in a resource-limited setting.

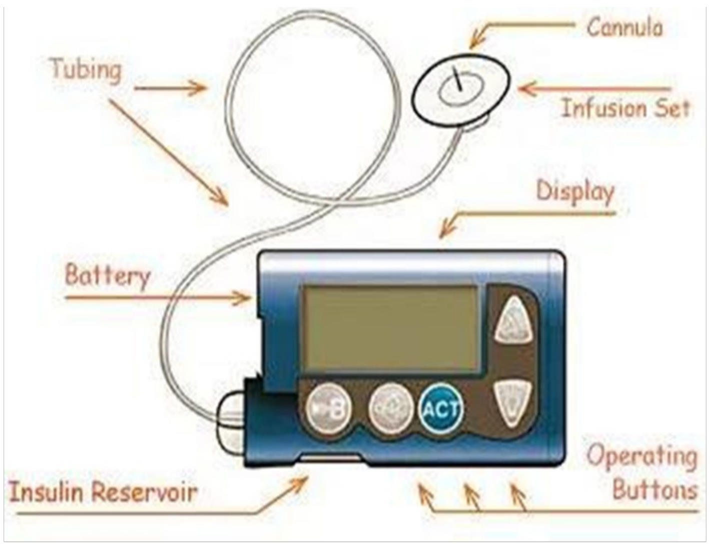

FIG. 3: An Insulin Pump Model

CONTROL ALGORITHM

In commercially available continuous glucose monitoring (CGM) devices that utilize enzymatic sensors, algorithms are essential for converting the measured electrical current into glucose values. These algorithms not only translate interstitial glucose (IG) readings to approximate blood glucose (BG) levels—accounting for differences in their linear ranges but also help minimize the typical 10–15-minute lag between tissue and Blood glucose levels.

To enhance the detection of hypoglycaemia, an important early step is improving calibration algorithms. These refined algorithms enable more accurate estimation of actual blood glucose levels, allowing for quicker and more reliable identification of low glucose episodes.

Following improvements in CGM accuracy—achieved through advanced sensors and more sophisticated calibration algorithms—another crucial step in enhancing the quality of life for people with diabetes (PwD) is the implementation of predictive algorithms and alarm systems. These features enable early detection of impending hypoglycaemia, allowing patients to take timely action and effectively prevent low glucose episodes.

Mode Of Action:

Glucose Sensor (CGM)

Real-Time Glucose Data

Control Algorithm

Calculates Insulin Needs
Insulin Pump

Delivers Insulin Subcutaneously

Glucose Levels Change → Back to CGM

Applications

*Type 1 Diabetes management
*Pediatric diabetes care
*Transition care from adolescence to adulthood
*Diabetes management during pregnancy
*Support during illness or stress
*Nighttime glucose monitoring
*Remote patient monitoring via apps/cloud
*Use in schools and workplaces for consistent control
*Training/education tools for new patients
*Clinical trials and research on automated insulin delivery

CLINICAL EVIDENCE AND PERFORMANCE

Real-World Evidence of the Cambridge Hybrid Closed-Loop App with FreeStyle Libre 3

Hybrid closed-loop (HCL) systems represent a major advance in type 1 diabetes care, combining continuous glucose monitoring with automated insulin delivery. Most available systems are limited to specific devices, reducing patient choice. The integration of the FreeStyle Libre 3 sensor with the Cambridge hybrid closed-loop app (CamAPS FX) and YpsoPump provides the first interoperable system that allows users to select from multiple sensors and pumps, giving more flexibility and personalization.

This study assessed the real-world performance of this system in Germany. Data were collected from the first group of users, including both adults and children, during everyday use. The analysis focused on glucose management, time within the target range, time above or below range, and the extent of automated insulin delivery.

The findings showed that the system effectively maintained glucose within recommended targets across different age groups. Adults tended to have slightly better outcomes, while children experienced greater variability due to differences in insulin sensitivity, activity, and diet. Importantly, automated insulin delivery was used for the majority of the time, highlighting the reliability and practicality of the system in daily life.

Outcomes were comparable to those observed in clinical trials and consistent with other real- world studies of hybrid closed-loop systems. Despite some limitations, such as a relatively small sample size and short duration, this study provided valuable insights by including a wide range of participants, including young children.

In conclusion, the Cambridge hybrid closed-loop app with FreeStyle Libre 3 and YpsoPump is effective, user-friendly, and supports broader adoption of flexible, interoperable diabetes technologies.

COMPLIANCE WITH ETHICAL STANDARDS

Eighteen-Month Hybrid Closed-Loop Use in Very Young Children with Type 1 Diabetes

This extension study investigated the long-term safety and effectiveness of the Cambridge hybrid closed-loop (HCL) insulin delivery system in very young children with type 1 diabetes. The trial followed participants from an earlier short-term study and extended CL use for a further 18 months across several European centers.

Children entering the extension had recently completed a randomized trial comparing CL therapy with sensor-augmented pump therapy. Those who continued into the extension phase remained on CL treatment throughout. The study aimed to assess whether the short-term improvements in blood glucose management could be sustained over a much longer period.

Results showed that CL therapy maintained stable glucose control, with outcomes remaining consistent with or better than those seen in the earlier trial. Most children met recommended targets for glucose management, and many achieved more stringent international standards. Importantly, these improvements were achieved without any increase in episodes of low blood sugar. Insulin delivery patterns also shifted, with the system adapting dosing between meals and background requirements.

Safety findings were reassuring, with very few severe events reported, no diabetic ketoacidosis, and only one device-related issue, which was quickly corrected. Families reported high use of the system over the entire study period, indicating strong long-term acceptability and practicality in daily life.

In conclusion, the study demonstrated that hybrid closed-loop therapy can deliver sustained benefits in very young children with type 1 diabetes, offering both effective and safe glucose management during a critical stage of growth and development.

Use of Advanced Hybrid Closed-Loop System during Pregnancy:

Pregnant women with type 1 diabetes are at high risk of maternal and neonatal complications, making strict glucose management essential. Achieving recommended targets is difficult due to hormonal changes, insulin resistance, and daily fluctuations in requirements.

This case describes a woman with long-standing diabetes who switched from conventional insulin pump therapy to the advanced hybrid closed-loop (AHCL) system during early pregnancy. The system provides automated insulin delivery with frequent corrections, while still requiring meal announcements. Before the switch, she experienced unstable control and frequent glucose fluctuations despite dietary adjustments. After adopting AHCL, her glucose stability improved, with fewer episodes of low blood sugar.

During the later stages of pregnancy, hormonal shifts created new challenges, leading to difficulties in keeping glucose within the desired range. To address this, her care team introduced changes in meal planning, adjusted insulin timing, and developed strategies such as modifying food intake to optimize system responses. These adaptations helped restore stability until delivery.

A healthy baby was born at term, and the patient expressed overall satisfaction with the AHCL system, highlighting its ability to reduce hypoglycemia and ease daily management. However,

she also noted slower correction of high glucose after meals and the need for close medical support, particularly in the third trimester.

This case demonstrates the promise of AHCL systems in pregnancy. They provide improved control and safety compared to older methods, but their current algorithms adapt slowly to rapid physiological changes, emphasizing the need for further refinement and clinical studies.

Commercially available Hybrid Closed Loop System:

Commercially available mongrel closed circle systems include the following:

1. Medtronic,
2. Control- IQ,

3. Omnipod 5,
4. CamAPS FX.

Several mongrel closed- circle (HCL) insulin delivery systems are now available on the request, furnishing automatic insulin dosing grounded on nonstop glucose monitoring (CGM) data and algorithm- driven adaptations. These systems are designed to ameliorate blood sugar control, lower the threat of hypoglycaemia, and simplify diabetes operation for people with type 1 diabetes.

1. The Medtronic MiniMed 670G was the first system, using fixed targets and taking estimation. The MiniMed 780G offers customizable targets, automated corrections, and no- estimation GuardianTM 4.

2. Tandem's Control- Command system, which works with the tslim X2, uses Dexcom G6 to prognosticate glucose trends and includes Sleep and Exercise modes.

3. Omnipod® 5 is a tubeless insulin pump with an bedded algorithm, smartphone control, and blessing for use in type 1 and type 2 diabetes.

4. CamAPS FX is an Android app- grounded system that works with compatible pumps, is approved for use during gestation and in type 1 diabetes, and allows for malleable glucose targets.

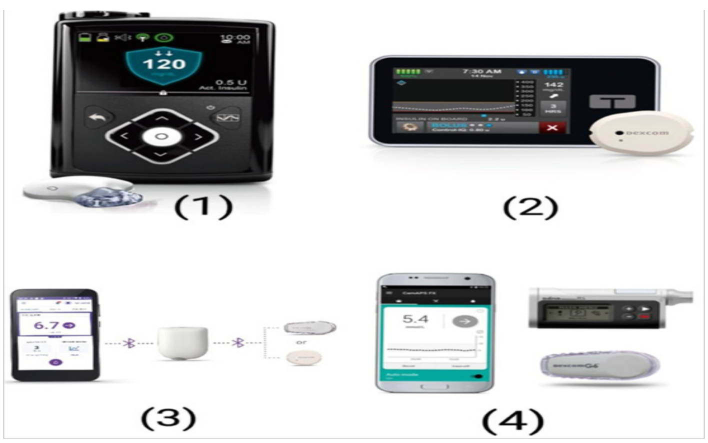

FIG. 4: (1) Medtronic, (2) Control-IQ, (3) Omnipod 5, (4) CamAPS FX

CONCLUSION

In conclusion, type 1 diabetes mellitus (T1DM) remains lifelong condition requiring careful glucose management to prevent acute and chronic problems. While conventional insulin therapy has long been the standard of care, its limitations such as hypoglycaemia risk, glycaemic variability, and patient burden have driven the evolution of advanced technologies. Automated Insulin Delivery (AID) systems, particularly Hybrid Closed Loop (HCL) systems, have developed as a major breakthrough, integrating CGM, insulin pumps, and sophisticated algorithms to optimize glycaemic control with minimal manual intervention. Clinical evidence demonstrates that HCL systems improve HbA1c, increase time in range, reduce hypoglycaemia, and enhance quality of life across various populations, including children, pregnant women, and adults. However, challenges remain, such as the need for meal boluses, cost and accessibility barriers, sensor accuracy limitations, and delayed insulin action post meals. Current research and technological innovation aim to improve algorithms, enhance system adaptability, and improve affordability to expand access globally. Finally, while HCL systems do not provide a fully autonomous artificial pancreas, they represent a significant step toward that goal, offering safer, more convenient and more effective diabetes management. Continued development, early adoption in high-risk groups, and health care policy support will be essential for maximizing their impact on T1DM care.

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