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專題報導

Continuous Glucose Monitoring (CGM): Real-Time CGM (rtCGM), Intermittently Scanned CGM (isCGM), and Closed-Loop Systems

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Abstract

Application of continuous glucose monitoring (CGM) in diabetes management involves real-time CGM (rtCGM), intermittently scanned CGM (isCGM), and automated insulin delivery (AID) associated closed-loop systems. The rtCGM provides continuous real-time glucose data and alerts, helping improve blood glucose control and reduce the risk of hypoglycemia. The isCGM, which requires manual scanning of the sensor to obtain data, has a more simplified function but remains practical for those not needing intensive insulin therapy. The AID system integrates CGM, insulin pumps, and algorithms to automatically adjust insulin doses, forming a closed-loop control that significantly enhances blood glucose stability. Research shows these technologies can effectively improve HbA1c, increase Time in Range (TIR), and reduce the risk of acute complications. In summary, despite challenges such as skin reactions, drug interference, and accessibility, the combination of continuous glucose monitoring and closed-loop systems enables personalized medical choices and plays an important role in empowering patients with diabetes.

Key Words: Continuous Glucose Monitoring, Automated Insulin Delivery, Time in Range

Continuous glucose monitoring (CGM) represents a pivotal advancement in diabetes technology, offering dynamic insights into glucose fluctuations beyond the snapshots provided by traditional blood glucose monitoring (BGM). CGM systems enable people with diabetes to see real-time or near-real-time glucose levels, trends, and patterns, which facilitates proactive self-management and treatment adjustments. Over the past decade, CGM has evolved into three major categories: real-time CGM (rtCGM), intermittently scanned CGM (isCGM) and professional CGM (Table 1). Based on rtCGM, automated insulin delivery (AID) systems or closed-loop systems, incorporates CGM data into insulin delivery algorithms, offering semi-autonomous glucose control (Figure 1) [1,2].

Real-Time Continuous Glucose Monitoring (rtCGM)

The rtCGM systems measure and display

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glucose values continuously. These systems include alarms for hypoglycemia and hyperglycemia and offer predictive alerts to reduce risks of glycemic excursions. rtCGM is particularly beneficial for people with type 1 diabetes and those on multiple daily insulin injections (MDI) or continuous subcutaneous insulin infusion (CSII)[3,4].

According to the 2025 ADA Standards, rtCGM is strongly recommended for youth and adults on any insulin therapy, with evidence demonstrating improvements in HbA1c, time in range (TIR), and reduced episodes of hypoglycemia [4,5]. Examples of FDA-approved rtCGMs include the Dexcom G6 and G7, Medtronic Guardian 4, and Simplera systems. These devices can be integrated with insulin pumps or connected insulin pens for enhanced data and therapy coordination[1,2].

Most rtCGM devices are factory-calibrated and classified as nonadjunctive, meaning they can be used for insulin dosing without confirmatory fingersticks, except in specific situations like sensor warm-up or signal loss [6].

Intermittently Scanned CGM (isCGM)

The isCGM systems measure glucose continuously but require users to scan the sensor with a reader or smartphone to view glucose levels. Some models, such as FreeStyle Libre 2 Plus and Libre 3, now include optional alarms, offering near-rtCGM functionality[7].

The isCGM is an effective and more affordable option compared to rtCGM, especially for those not requiring intensive insulin therapy. Benefits include improved testing frequency, user satisfaction, and

Table 1. Comparison of Continuous Glucose Monitoring (CGM)

Feature	Real-Time CGM (rtCGM)	Intermittently Scanned CGM (isCGM)	Professional CGM
Glucose Data Availability	Continuous and real-time display	Continuous measurement; display requires scanning	Retrospective (blinded/unblinded)
Alerts & Alarms	Yes (real-time hypo/hyperglycemia alerts)	Some models have optional alarms	No alerts (unless unblinded version used)
Data Viewing	Smartphone, receiver, or smartwatch	Requires manual scan to view readings	Data reviewed by healthcare provider
User Interaction	Minimal; passive glucose monitoring	Active; requires user scan	Minimal; mainly for provider insights
Data Use	Real-time decision-making, insulin dosing	Trend awareness, insulin dosing if nonadjunctive	Pattern analysis, treatment planning
Calibration	Factory calibrated (e.g., Dexcom G6/G7, Medtronic Guardian Connect, Rightest iFree, Freestyle Libre 3)	Factory calibrated (e.g., Libre 2)	Depends on device (e.g., Freestyle Libre Pro, Medtronic iPro2)
Duration of Wear	7–14 days depending on device	Typically 14 days	7–14 days
Cost and Insurance	Higher cost; often covered for insulin users	Generally lower cost	Billed through clinic or insurance
Population Use	Type 1, insulin-treated Type 2, pregnant, pediatric	Type 1, Type 2 (with/without insulin)	All diabetes types, especially for diagnostics
Integration with AID Systems	Yes (can be part of hybrid closed-loop systems)	Limited; some models now approved for integration	No integration

increased TIR, although fewer studies support its efficacy compared to rtCGM [8,9].

Professional and Over-the-Counter CGM

Professional CGM systems are owned by clinics and are typically worn by patients for 7–14 days to collect retrospective glucose data. These are either blinded or unblinded and are useful for pattern analysis when personal CGM is not feasible or available [9].

Additionally, over-the-counter (OTC) CGMs, such as biosensors, are emerging for individuals with prediabetes or non-insulin-treated diabetes. These devices provide insights into glucose responses to lifestyle without alarms or decision-support capabilities [10].

Benefits of CGM Technology

Extensive RCTs have demonstrated rtCGM's effectiveness in reducing HbA1c and increasing TIR among individuals with both type 1 and type 2 diabetes. These benefits occur without significantly increasing hypoglycemia risk and can persist for at least 12 months with consistent CGM use [3,4].

Studies in youth show that early CGM initiation improves glycemic control and quality of life, particularly when caregivers are involved in monitoring and management [11]. Similarly, seniors and adults on basal insulin benefit from rtCGM in terms of improved A1c and fewer glucose excursions [12].

The isCGM, while slightly less studied, has also shown benefit in reducing hypoglycemia and increasing TIR in insulin-treated type 2 diabetes and certain type 1 diabetes populations [13].

Users of both rtCGM and isCGM report improved treatment satisfaction, confidence in glucose management, and reduced diabetes-related distress. Predictive alerts in rtCGM provide a sense of safety, especially overnight and during physical activity [14].

Real-world data indicate that CGM use reduces acute complications such as diabetic ketoacidosis (DKA), severe hypoglycemia, and hospitalizations for hyperglycemia, particularly when CGM is consistently used over time [15,16].

CGM systems provide comprehensive data, including ambulatory glucose profiles (AGP), TIR, time below range (TBR), time above range (TAR), and glucose variability. These metrics support more nuanced decisions than HbA1c alone. The ADA recommends using standardized CGM reports in both clinical and self-management settings. Devices should be capable of generating one-page summary reports, weekly overviews, and raw data downloads[17].

Closed-Loop (Automated Insulin Delivery) Systems

Closed-loop or automated insulin delivery (AID) systems integrate CGM data with insulin pump delivery via algorithms. These algorithms adjust insulin delivery in real-time based on glucose trends, aiming to maintain glucose within a target range without manual input [1].

The three core components are (Figure 1):

1. Insulin pump – Delivers insulin in adjustable microdoses.

2. CGM sensor – Continuously monitors interstitial glucose.

3. Control algorithm – Modulates insulin delivery based on CGM data and predicted trends.

Some AID systems include meal detection features or allow for manual carb entries to enhance postprandial insulin delivery. All current AID systems require some user interaction for meals or correction boluses [2].

AID systems approved by the FDA include t:slim X2 with Control-IQ, Omnipod 5, iLet Bionic Pancreas, Medtronic 670G, 770G, and 780G, and Beta Bionics iLet. These systems integrate with rtCGMs such as Dexcom G6/G7, Libre Libre 3 Plus,

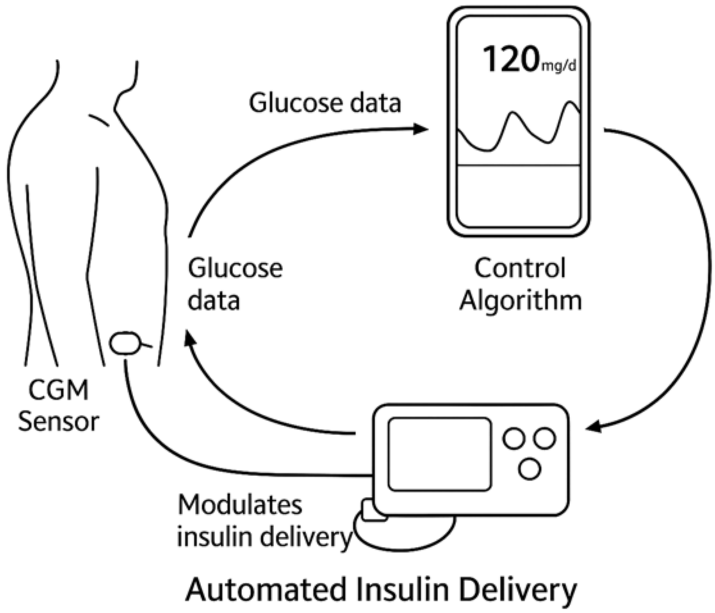

Figure 1.

and Medtronic Guardian sensors. Some, like the iLet, use adaptive algorithms that require minimal input from users[18,19].

AID systems have demonstrated superior outcomes compared to both MDI and traditional insulin pump therapy. Benefits include higher TIR (target glucose: 70–180 mg/dL), reduced A1c, and lower incidence of hypoglycemia. These results are consistent across various age groups and diabetes types [20]. In children, AID systems initiated soon after diagnosis improve long-term glycemic control, decrease A1c, and improve caregiver confidence and satisfaction. In pregnancy, rtCGM has been shown to improve maternal TIR and reduce neonatal complications, such as macrosomia and neonatal hypoglycemia. Older adults benefit from AID systems through safer glucose control and fewer hypoglycemia episodes. The ADA recommends continued access to AID regardless of age or A1c level.

Contact dermatitis is a common adverse effect from CGM adhesives, often linked to isobornyl acrylate. Management includes barrier sprays, changing adhesive brands, or switching to implantable sensors like the Eversense E3. Besides, several medications can interfere with CGM accuracy, such as acetaminophen, ascorbic acid, hydroxyurea, mannitol, and sorbitol. Users should be educated about these interactions and advised to use BGM when accuracy is questioned.

Successful CGM and AID use requires comprehensive training for both users and healthcare providers. The ADA emphasizes ongoing education, device literacy, and periodic reassessment of user competency to ensure optimal outcomes.

Despite proven benefits, CGM and AID adoption remain inconsistent due to cost, insurance coverage, digital literacy, and healthcare infrastructure. Addressing these disparities is essential to reducing the burden of diabetes complications, particularly in underserved populations.

Conclusion

Continuous glucose monitoring and automated insulin delivery systems have transformed diabetes care by enabling precise, dynamic glucose management. rtCGM, isCGM, and AID technologies have demonstrated significant improvements in glycemic control, quality of life, and complication prevention.

Integrating these technologies with personalized care, education, and equitable access will be key to maximizing their benefits across all populations.

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連續血糖監測：
即時型、間歇掃描型與閉環系統

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摘　要

連續血糖監測（CGM）在糖尿病管理中的應用，包括即時型（rtCGM）、間歇掃描型（isCGM）及自動胰島素輸注（AID）閉環系統。rtCGM 可提供連續即時血糖數據及警示，有助於提升血糖控制與減少低血糖風險；isCGM 則需主動掃描感測器以取得資料，雖功能較為簡化，仍對不需密集胰島素治療者具實用性。AID 系統則結合 CGM、胰島素幫浦及演算法，可自動調整胰島素劑量，形成閉環控制，大幅提升血糖穩定性。研究顯示，這些技術能有效改善 HbA1c、增加目標範圍內時間（TIR），並降低急性併發症風險。總結來說，即使有皮膚反應、藥物干擾與可近性等挑戰，連續血糖監測合併閉環系統，已可做到個別化醫療選擇與具備提升糖尿病患賦能的重要性。