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CLINICAL EFFICACY, GLYCEMIC OUTCOMES, AND PATIENT ACCEPTABILITY OF CONTINUOUS GLUCOSE MONITORING SYSTEMS IN PEDIATRIC TYPE 1 DIABETES: A SYSTEMATIC REVIEW

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ABSTRACT

Background: Background: Continuous glucose monitoring (CGM) has fundamentally transformed the management of type 1 diabetes (T1D) in pediatric populations by providing frequent interstitial glucose measurements and temporal trends. However, clinical efficacy and patient acceptability remain heterogeneous across studies regarding age, technology generation, and treatment regimens.
Aim: This systematic review aimed to evaluate the clinical efficacy, glycemic outcomes, and patient acceptability of CGM systems in pediatric patients with T1D, focusing on changes in HbA1c, CGM-derived metrics, hypoglycemia reduction, and quality of life.
Methods: Conducted in accordance with PRISMA guidelines, a systematic literature search across multiple databases identified prospective interventional and observational studies evaluating CGM use in children and adolescents aged <18 years diagnosed with T1D. Twenty-nine studies meeting the inclusion criteria were analyzed.
Results: CGM use demonstrated meaningful improvements in glycemic metrics, particularly increasing Time in Range (TIR), reducing Time Below Range (TBR) and Time Above Range (TAR), decreasing glycemic variability, and enhancing the detection of asymptomatic and nocturnal hypoglycemia. While HbA1c reductions varied—being most pronounced in participants with higher baseline values—the greatest metabolic and glycemic benefits were consistently observed with regular, sustained sensor use and when CGM was integrated into automated insulin delivery (AID) systems. Patient and caregiver satisfaction was generally high, though practical challenges such as local skin reactions, adhesive failures, sensor discomfort, and alarm burden were documented.
Conclusions: CGM is a valuable component of pediatric T1D management, providing essential glycemic insights beyond HbA1c alone. Its clinical effectiveness relies heavily on consistent sensor adherence, appropriate education, family engagement, and the integration of technology into daily therapeutic decisions.

KEYWORDS

Continuous Glucose Monitoring (CGM), Type 1 Diabetes, Pediatric Patients, Glycemic Control

CITATION

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1. Introduction

Type 1 diabetes (T1D) is one of the most common chronic endocrine disorders in children and adolescents and requires lifelong insulin therapy together with continuous monitoring of glucose levels. Achieving and maintaining adequate glycemic control during childhood is particularly challenging because of physiological growth, hormonal changes, variable insulin sensitivity, unpredictable physical activity, dietary variability, and the increasing autonomy of young patients. Inadequate glycemic control is associated with an increased risk of both acute complications, including hypoglycemia and diabetic ketoacidosis, and long-term microvascular and macrovascular complications. Consequently, regular assessment of glucose levels and optimization of insulin therapy remain fundamental components of pediatric diabetes management [1,2].

Continuous glucose monitoring (CGM) has substantially changed the approach to glucose monitoring in pediatric T1D. Unlike conventional blood glucose monitoring, CGM systems provide frequent measurements of interstitial glucose and allow patients, caregivers, and healthcare professionals to evaluate not only individual glucose values but also temporal trends and patterns of glycemic variability. Current pediatric diabetes recommendations support the use of CGM in children and adolescents with T1D, with real time CGM (rtCGM) and intermittently scanned CGM (isCGM) increasingly incorporated into routine clinical care. The benefits of CGM are closely related to consistent sensor use, and current recommendations emphasize the importance of sustained access to and utilization of these technologies [2,3].

The assessment of CGM-derived metrics has also expanded beyond glycated hemoglobin (HbA1c). Time in range (TIR), defined as the percentage of time spent between 70 and 180 mg/dL, together with time below range (TBR), time above range (TAR), and measures of glycemic variability such as coefficient of variation (CV), provide additional information about daily glucose control. International pediatric recommendations generally aim for TIR above 70%, TBR below 4%, and TAR above 180 mg/dL below 25%, while minimizing exposure to clinically significant hypoglycemia [1]. These parameters may therefore provide a more detailed assessment of the clinical effects of CGM than HbA1c alone.

Evidence from pediatric clinical trials, however, indicates that the effectiveness of CGM may vary according to age, baseline glycemic control, treatment regimen, and the extent to which the technology is used. In the Start-In! randomized controlled trial, which included children and adolescents aged 2–17 years, different strategies of rtCGM use did not result in a significant difference in longitudinal HbA1c compared with conventional blood glucose monitoring, despite the potential benefits of more intensive glucose information [4]. Similarly, a randomized trial conducted in young children demonstrated that rtCGM did not significantly improve the primary HbA1c outcome compared with standard glucose monitoring, highlighting the importance of age and patterns of technology use when interpreting CGM efficacy [5]. These findings suggest that the clinical effectiveness of CGM cannot be adequately characterized by a single metabolic endpoint.

In addition to metabolic outcomes, patient and caregiver acceptability has become an increasingly important aspect of CGM evaluation. Pediatric diabetes management takes place within a family context, and factors such as treatment burden, fear of hypoglycemia, sleep disruption, family conflict, device visibility, alarms, skin reactions, and concerns related to wearing a sensor may influence sustained CGM use. A systematic review of psychological outcomes in pediatric patients found that CGM technologies may improve several patient and family reported outcomes, including treatment satisfaction, quality of life, diabetes distress, and fear of hypoglycemia, although the magnitude and consistency of these effects varied between studies [6]. In children younger than 7 years, caregiver reported evaluations have also demonstrated high satisfaction with rtCGM therapy and perceived benefits for daily functioning and sleep, emphasizing the importance of caregiver experience when evaluating CGM in younger populations [7].

Despite the growing availability of CGM systems and the increasing number of pediatric studies, the evidence remains heterogeneous with respect to patient age, CGM technology, duration of use, comparator treatment, metabolic endpoints, and patient reported outcomes. Moreover, clinical efficacy and patient

acceptability are often evaluated separately, although both dimensions may influence the real world effectiveness and sustained use of CGM. A comprehensive assessment of these outcomes is therefore important for understanding the overall clinical value of CGM systems in children and adolescents with T1D.

The aim of this systematic review was to evaluate the clinical efficacy, glycemic outcomes, and patient acceptability of CGM systems in pediatric patients with T1D. Particular attention was given to changes in HbA1c and CGM-derived metrics, including TIR, TBR, TAR, and glycemic variability, as well as hypoglycemia, diabetic ketoacidosis, quality of life, treatment satisfaction, device related problems, and other factors influencing the acceptability and sustained use of CGM technology.

2. Methodology

2.1. Participants

The research inclusion criteria were structured based on the PICOS framework (population, intervention, comparison, outcome, and study design) in accordance with the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). The selected articles aimed to answer the following research question: "Clinical Efficacy, Glycemic Outcomes, and Patient Acceptability of Continuous Glucose Monitoring Systems in Pediatric Type 1 Diabetes?". The main inclusion criteria were as follows: (1) prospective primary interventional and observational studies, including randomized controlled trials (RCTs), non-randomized controlled trials, quasi-experimental studies, prospective cohort, cross-over, single-arm observational, pilot, feasibility, and acceptability studies; (2) a population of children and adolescents aged <18 years diagnosed with type 1 diabetes mellitus (T1D); (3) documented application of continuous glucose monitoring (CGM) systems, including real-time continuous glucose monitoring (rtCGM) or intermittently scanned continuous glucose monitoring (isCGM / Flash Glucose Monitoring [FGM]); (4) inclusion of a comparator group using self-monitoring of blood glucose (SMBG / capillary blood glucose testing), previous generation CGM devices, or no CGM use (with a comparator not required for single-arm, pilot, feasibility, or acceptability studies); (5) measurement of clinical and glycemic outcomes including HbA1c levels, Time in Range (TIR: 70–180 mg/dL), Time Below Range (TBR: <70 mg/dL and <54 mg/dL), Time Above Range (TAR: >180 mg/dL), glucose variability (CV %), incidence of severe hypoglycemia, diabetic ketoacidosis (DKA), hypoglycemia unawareness, and nocturnal hypoglycemia; and (6) reporting of technological characteristics, feasibility, or patient-reported outcomes (PROMs) such as measurement accuracy (MARD %), sensor wear time, device failures, skin/dermatological reactions, health-related quality of life (HRQoL), hypoglycemia fear/anxiety, alarm fatigue, treatment satisfaction, and overall acceptability among pediatric patients and their caregivers. The exclusion criteria were as follows: (1) systematic reviews, meta-analyses, scoping reviews, and narrative reviews; (2) study protocols and retrospective studies; (3) case reports; and (4) conference abstracts lacking sufficient numerical data.

2.2. Data collection and analysis

The literature selection process was carried out in multiple stages, strictly following PRISMA guidelines. Initially, a team of four independent reviewers assessed the titles and abstracts of 539 articles, examining their compliance with the main objective of the study. To ensure maximum objectivity and minimize systematic error, this stage was conducted independently on the Rayyan platform. Studies that failed to meet the basic assumptions of the PICOS protocol were excluded. The next step involved an independent full-text assessment of the remaining publications by all review authors, based on detailed inclusion and exclusion criteria. Potential disagreements and conflicting assessments were subjected to joint analysis and discussed until a final consensus was reached. Twenty-nine studies were included in this systematic review. Of these, 8 were randomized controlled trials (RCTs) or randomized crossover trials.

2.3. Data Extraction

The following data were extracted from the qualified publications:DOI identifier, author and year of publication, total number of studied patients (N), control group size (N), patient characteristics: age (mean, median, and range), gender of study participants, country where the study was conducted, study setting (e.g., clinical center, clinic), study duration or follow-up period, intervention details including type and model of CGM systems (e.g., Dexcom G6, FreeStyle Libre), comparator group (e.g., use of blood glucose meter [BGM] or older systems), technical parameters of the used CGM systems such as accuracy (MARD in %), alarm settings (thresholds and predictive) and data transmission method, calibration frequency and mode (e.g., required capillary blood calibration vs. factory calibration), tools used to measure glycemic outcomes (e.g., laboratory tests, programs like Clarity), glycemic outcomes regarding glycated hemoglobin (HbA1c) level, glycemic outcomes defining time in ranges: TIR, TBR, TAR, and glycemic variability (CV), episodes of severe hypoglycemia and diabetic ketoacidosis (DKA), impact on quality of life and patient acceptability (PROMs) based on dedicated measurement scales, frequency of sensor failure, skin reactions and percentage of sensor wear time, occurrence of hypoglycemia symptoms (autonomic and neuroglycopenic), assessment of hypoglycemia unawareness, reported dermatological and local symptoms in the sensor area, conclusions from the analyzed study.

3. Results

3.1. Technical Specifications and Intervention Characteristics

The technical characteristics and intervention strategies of the CGM systems varied considerably across the included studies. Both real time continuous glucose monitoring (rtCGM) and intermittently scanned/flash glucose monitoring (isCGM/FGM) systems were represented, with rtCGM being the predominant technology. The most frequently investigated systems included Dexcom G5 and G6, Medtronic Enlite, Guardian Sensor 3, FreeStyle Navigator, FreeStyle Libre, and earlier generation MiniMed/Medtronic CGM systems [8,10,12,13,14,16,18,19,23,25,26,30,34,35,36]. More recent studies also evaluated newer systems, including FreeStyle Libre 3 integrated with the CamAPS HX fully closed loop system, Dexcom G6 integrated with the Tandem t:slim X2 and Control-IQ algorithm, and the Linx CGM system [17,29,33]. In contrast, several studies did not specify the exact CGM model or technical characteristics, particularly observational studies in which CGM use rather than a specific device was the primary intervention [11,24,27,28].

The comparator and intervention designs were also heterogeneous. Several studies compared CGM directly with conventional blood glucose monitoring (BGM/SMBG) [8,12,13,14,23,31,32,34,36], whereas others compared immediate versus delayed CGM initiation [16,25,30], different frequencies of CGM use [19,24,27], or baseline values with outcomes obtained after CGM initiation [10,17,18,20,26,28]. Some investigations evaluated CGM as an integral component of sensor augmented pump therapy or automated insulin delivery (AID), including systems incorporating low glucose suspend or predictive low glucose suspend functions [20,23,25,30], as well as hybrid or fully closed loop approaches [29,33]. The duration of CGM exposure ranged from short term interventions of several days to long term use over 6–12 months, with some studies incorporating run in periods or repeated CGM assessments [8,12,15,17,18,22,23,26,27,29,33–36].

Substantial differences were observed in the technical specifications of the devices. Older CGM systems, such as Dexcom G5, generally required capillary glucose calibration, commonly twice daily, whereas newer factory calibrated systems such as Dexcom G6, FreeStyle Libre 3, and Linx did not require routine finger stick calibration [8,13–15,29,33]. Earlier systems, including FreeStyle Navigator, Medtronic Enlite, and MiniMed CGMS, also required calibration using capillary blood glucose measurements, although the exact calibration frequency was frequently not reported [12,18,25,26,31,32,34–36]. Data transmission and alarm functionality varied according to device generation. Modern rtCGM systems provided continuous transmission to dedicated receivers or smartphone applications and allowed configurable alerts for hypo- and hyperglycemia, with some systems additionally supporting remote data sharing with caregivers [10,13,15,16,23,29,33]. In contrast, professional or blinded CGM systems, such as the iPro2, stored glucose data for subsequent clinical analysis and did not provide real time transmission or alarms [12,31].

The reported technical parameters were not consistently available across studies. MARD was explicitly reported only rarely, while in many studies the accuracy parameters, alarm thresholds, and transmission characteristics were either not assessed or not reported [11,13,14,18,19,22–24,26,27,30,32,34–36]. Where available, sensor duration ranged from approximately 7 days for earlier Dexcom systems to 10 days for Dexcom G6, while some interventions used CGM or flash monitoring for shorter predefined periods, such as 3–5 days with professional CGM or 14 days with FGM [8,12,14,15,17]. Overall, the included studies encompassed a broad spectrum of CGM technologies, from early retrospective and intermittently scanned systems to contemporary factory calibrated rtCGM devices integrated with automated insulin delivery, reflecting substantial technological evolution over the period covered by the review.

3.2. Glycemic Outcomes and Metabolic Control Parameters

Glycemic outcomes varied across the included studies according to study design, participant age, baseline glycemic control, duration and frequency of sensor use, and whether CGM was evaluated as a standalone monitoring method or as part of an automated insulin delivery system. HbA1c was the most frequently reported metabolic outcome, whereas CGM-derived metrics, including time in range (TIR), time below range (TBR), time above range (TAR), and coefficient of variation (CV), were reported mainly in more recent studies.

Several controlled studies demonstrated improvements in glycemic control with CGM compared with conventional blood glucose monitoring. In the CITY randomized trial, adolescents and young adults using CGM achieved a greater reduction in HbA1c than those using BGM, with an adjusted between-group difference of −0.37 percentage points after 26 weeks. CGM use was also associated with higher TIR (43% vs 35%), lower TBR (2.2% vs 3.2%), lower TAR (54% vs 61%), and lower glycemic variability expressed as CV (39% vs 42%) [8]. Follow-up of this cohort indicated that the glycemic benefits of CGM were maintained over 12 months among participants who continued using the technology. Participants who switched from BGM to CGM also experienced improvements in HbA1c and TIR after CGM initiation [14]. Similarly, the DirecNet study reported a modest reduction in HbA1c from 7.1% to 6.8% after 13 weeks of continuous monitoring [26].

The magnitude of improvement was generally greater among participants with higher baseline HbA1c. In a real-world study of the Linx CGM system, HbA1c decreased from 9.5% to 8.1%, while TIR increased from 49.8% to 60.0%. TBR at 54–69 mg/dL decreased from 3.0% to 1.0%, and time below 54 mg/dL decreased from 1.0% to 0.5% [15]. In the Cameroonian pilot study, median HbA1c decreased from 10.0% at baseline to 9.3% after three months, although overall glycemic control remained suboptimal, with a reported TIR of 26% [28]. Professional CGM combined with therapeutic adjustment also reduced HbA1c from 8.01±1.46% to 7.47±0.91% after three months [12]. Observational studies further showed that more frequent or sustained CGM use was associated with lower HbA1c, whereas intermittent or infrequent sensor use was linked to less favorable glycemic outcomes [11,19,24,27].

Not all studies demonstrated a significant improvement in HbA1c. In young children enrolled in the SENCE study, CGM-based interventions did not produce a sustained between-group difference in HbA1c, although changes in selected CGM-derived metrics, particularly reductions in hypoglycemic exposure and glycemic variability, were observed [13]. Similarly, initiating CGM shortly after T1D diagnosis did not significantly improve HbA1c compared with later initiation, and motivational stage at CGM initiation was associated with current but not subsequent glycemic control [16,25,30]. Earlier trials in children and adolescents also reported either modest reductions or no significant between-group differences in HbA1c, particularly when sensor adherence was limited [32,34–36].

Studies evaluating CGM as part of automated or closed-loop insulin delivery generally demonstrated more pronounced improvements in CGM-derived metrics than studies assessing monitoring alone. In the randomized trial by Abraham et al., hybrid closed-loop therapy increased TIR from 53.1% to 62.5%, compared with an increase from 54.6% to 56.1% in the control group [23]. Smartphone-based automated insulin delivery produced a numerically higher TIR than sensor-augmented pump therapy (63.5% vs 57.3%), although the difference was not statistically significant in the small feasibility study [21]. Fully closed-loop insulin delivery also improved TIR compared with pump therapy combined with CGM, despite no statistically significant difference in HbA1c between the interventions [29]. These findings indicate that CGM-derived parameters may identify short-term improvements in daily glycemic control that are not always reflected by changes in HbA1c.

Relationships between individual CGM metrics were also examined. TIR was inversely associated with HbA1c, whereas higher TAR and glycemia risk index values were associated with poorer overall glycemic control [17,20]. TBR provided additional information that was not fully captured by HbA1c and was particularly relevant for identifying exposure to hypoglycemia [17]. Across the reviewed studies, the most consistent metabolic benefits were observed among participants who used CGM regularly and among those receiving CGM-integrated automated insulin delivery. Nevertheless, heterogeneity in outcome definitions, glucose thresholds, follow-up duration, device generation, and adherence limited direct comparisons between studies.

3.3. Safety Profile, Acute Complications, and Hypoglycemic Events

3.3.1 Reduction of hypoglycemia and symptom awareness

The implementation of continuous glucose monitoring (CGM) systems is associated with an effective reduction in patients' exposure to hypoglycemic episodes. Numerous studies have noted a sustained and statistically significant decrease in the time spent in hypoglycemia (TBR <70 mg/dL) and clinically significant hypoglycemia (TBR <54 mg/dL) compared to baseline values or traditional blood glucose monitoring (BGM) from capillary blood [8, 13, 14, 15, 23]. Furthermore, in one study, the median number of monthly low glucose events dropped from 5 to 0 after the implementation of a modern rtCGM system [15].

CGM devices demonstrate particular utility in detecting hidden, asymptomatic, and nocturnal hypoglycemic incidents, which can account for 70% to as much as 85% of all episodes identified during the night [12, 32]. Despite this, nocturnal hypoglycemia remains a clinical challenge; one study showed that the TBR percentage between 0:00 and 6:00 was 16.9% and was significantly higher than during the day [17]. Children with impaired hypoglycemia awareness (occurring in approx. 43% of participants in one cohort) are at particular risk, as all severe hypoglycemic episodes were found to occur in this group [18].

3.3.2 Acute complications: Severe hypoglycemia and diabetic ketoacidosis (DKA)

The incidence of acute complications when using CGM systems in children and adolescents is generally low [8, 13, 14, 21, 36]. Long-term observation noted a drastic decrease in hospitalizations and severe neurological events related to hypoglycemia. In one study, the rate of seizures decreased from 22 to 0 per 100 patient-years, and coma incidents were reduced from 4 to 0 per 100 patient-years [18]. Study results also indicate the high safety of short-term and closed-loop systems, where no episodes of severe hypoglycemia, seizures, or ketoacidosis were observed [21, 23]. Moreover, CGM systems proved to be feasible and reliable in a hospital setting, even during the acute treatment of pediatric diabetic ketoacidosis (DKA) in an intensive care unit [22].

3.3.3 Local safety and dermatological symptoms

CGM systems are considered safe, and reported device failures are mostly not associated with any serious adverse events [8]. The main issue affecting treatment tolerance is local and dermatological symptoms caused by the sensors. Local skin redness was reported in 33.3% and irritation in 40% of the examined children [12]. Severe allergic reactions to the sensor adhesive, pain, and physical discomfort were among the main reasons for patients completely discontinuing CGM therapy [18, 19, 26]. More severe complications, such as insertion site infections requiring emergency department (ED) intervention, occur extremely rarely [33]. On the other hand, in some patients, tolerance is high enough that there are no treatment dropouts due to skin problems, demonstrating significant inter-individual variability and differences between device models [15].

3.4. Patient-Reported Outcomes (PROMs), Device Acceptability, and Local Adverse Events

Patient-reported outcomes (PROMs), device acceptability, and the occurrence of local adverse events play a pivotal role in determining the long-term success and clinical utility of continuous glucose monitoring (CGM) systems in pediatric populations [12, 18, 19]. Overall device satisfaction and user acceptance remain high among children, adolescents, and their caregivers, as CGM effectively mitigates the burden of routine finger-prick blood glucose testing and offers reassuring visibility into glycemic trends [13, 14, 15]. Studies frequently highlight that sustained engagement translates into high adherence rates, with active sensor wear-time percentages commonly exceeding 80% to 90% of the monitoring duration over extended follow-up periods of 6 to 24 months [9, 10, 13, 14, 15, 18, 21, 25, 26].

Despite high general acceptance, device-related barriers and local dermatological complications are documented across clinical trials [12, 18, 26]. Local skin reactions—including adhesive irritation, localized

contact dermatitis, erythema, and mild pruritus—are reported in a subset of patients, with specific cohorts noting local redness in approximately 33.3% and skin irritation in 40.0% of participants [12]. Severe localized reactions or infections requiring clinical intervention are rare but occasionally necessitate temporary device removal [18, 26, 33]. Furthermore, technical challenges such as sensor detachment, adhesive failure, probe displacement, and smartphone connectivity issues contribute to device discontinuation or reduced wear time in a minority of users, underscoring the ongoing need for improved sensor adhesives and ergonomic designs tailored to active pediatric lifestyles [12, 18, 19, 29].

4. Discussion

This systematic review demonstrates that CGM can improve glycemic management in children and adolescents with T1D, although the magnitude of benefit varies considerably between studies. The most consistent improvements involved TIR, TBR, TAR, and glycemic variability, whereas reductions in HbA1c were less uniform. CGM use was also associated with a generally favorable safety profile and high levels of satisfaction among pediatric patients and their caregivers. However, the effectiveness of the technology depended strongly on regular sensor use, integration with insulin delivery, baseline glycemic control, and the ability of patients and families to respond appropriately to the information provided by the device.

The findings support the increasing emphasis on CGM-derived metrics as complementary outcomes to HbA1c. HbA1c remains an important measure of average glycemic exposure but does not reflect glucose fluctuations, the timing of hypo- or hyperglycemia, or differences between daytime and nocturnal control. In the included studies, clinically relevant improvements in TIR, TBR, TAR, and CV were sometimes observed without a statistically significant change in HbA1c [13,21,29]. This was particularly evident in studies of automated and closed-loop insulin delivery, in which CGM data enabled more responsive insulin adjustment and improved daily glucose profiles [21,23,29]. These findings are consistent with contemporary recommendations emphasizing the combined interpretation of HbA1c and CGM-derived metrics in pediatric diabetes care [1–3].

The greatest metabolic improvements were generally observed among participants with higher baseline HbA1c and among those who used CGM consistently. Substantial reductions in HbA1c were reported in real-world and pilot studies involving populations with initially suboptimal glycemic control [12,15,28]. Conversely, studies enrolling children with relatively favorable baseline values or evaluating early CGM initiation did not always demonstrate significant between-group differences [13,16,25]. This suggests that the measurable effect of CGM may partly depend on the potential for improvement at baseline. Nevertheless, the absence of a marked HbA1c reduction should not be interpreted as a lack of clinical benefit, particularly when CGM reduces exposure to hypoglycemia or improves glycemic variability.

Adherence emerged as a key determinant of treatment effectiveness. More frequent and sustained sensor use was associated with lower HbA1c and more favorable glycemic outcomes, whereas intermittent use reduced the potential benefits of CGM [11,19,24,27]. Earlier-generation devices required regular capillary calibration, had shorter sensor lifespans, and were more susceptible to discomfort, alarm burden, and technical interruptions. These limitations may partly explain the inconsistent findings reported in older pediatric studies [32,34–36]. Newer factory-calibrated systems provide longer sensor wear, continuous data transmission, configurable alarms, and remote glucose sharing. These technological advances may reduce treatment burden and facilitate greater involvement of caregivers, particularly in younger children.

Age and developmental stage remain important when interpreting CGM outcomes. Adolescents may benefit from greater autonomy and immediate access to glucose trends, but sustained use can be affected by competing daily activities, device visibility, alarm fatigue, and reduced parental supervision. In younger children, caregivers assume primary responsibility for interpreting CGM data and adjusting treatment. Therefore, the clinical value of CGM in this age group may include improved detection of nocturnal or asymptomatic hypoglycemia and greater caregiver reassurance, even when HbA1c remains unchanged [7,13]. Education and continued behavioral support are consequently essential, as access to glucose data alone does not ensure that patients and families can translate these data into effective therapeutic decisions.

The safety findings were generally reassuring. Severe hypoglycemia and DKA were uncommon, and several studies reported reductions in biochemical or clinically relevant hypoglycemia [8,13–15,18,23]. CGM was particularly useful for detecting nocturnal and asymptomatic episodes that could be missed by intermittent capillary measurements [12,17,32]. The technology also appeared feasible during inpatient treatment of

pediatric DKA, although evidence in this setting remains limited [22]. Importantly, CGM should be regarded as a tool supporting clinical assessment rather than an independent safeguard against acute complications. Its effectiveness still depends on sensor accuracy, appropriate alarm settings, user response, and access to confirmatory measurements when glucose values do not correspond with clinical symptoms.

Patient and caregiver acceptance was generally high, but favorable satisfaction scores coexisted with meaningful practical barriers. Continuous access to glucose trends reduced the burden of finger-prick testing and provided a greater sense of safety, particularly overnight [7,10,13–15,18]. At the same time, skin irritation, adhesive reactions, discomfort during insertion, sensor detachment, alarm burden, and connectivity problems reduced wear time or led to discontinuation in some participants [12,18,19,26,29]. Acceptability should therefore not be treated as a secondary outcome. Because sustained use is closely linked to metabolic effectiveness, device comfort, usability, and psychosocial compatibility are integral components of clinical efficacy.

Integration of CGM with automated insulin delivery produced some of the most favorable results in the reviewed evidence. Hybrid and fully closed-loop systems improved TIR and reduced hyperglycemic exposure more consistently than monitoring alone [21,23,29]. However, these effects cannot be attributed exclusively to the CGM component, because they also reflect automated insulin-adjustment algorithms and pump performance. Future evaluations should distinguish the benefits of glucose monitoring itself from those resulting from its incorporation into a broader therapeutic system. Comparisons between standalone CGM, sensor-augmented pump therapy, predictive low-glucose suspend systems, and hybrid or fully closed-loop treatment would facilitate more precise clinical interpretation.

This review has several limitations. The included studies differed substantially in design, sample size, participant age, baseline HbA1c, treatment regimen, CGM generation, comparator, follow-up duration, and outcome definitions. The evidence included randomized trials, observational studies, pilot investigations, and short-term feasibility studies, limiting direct comparison and precluding uniform conclusions regarding effect magnitude. TIR, TBR, and TAR were not consistently reported, particularly in older studies, and thresholds sometimes differed between publications. Device adherence, alarm settings, caregiver involvement, and previous experience with diabetes technology were also incompletely described. In addition, some studies evaluated CGM as part of automated insulin delivery, making it difficult to isolate the independent effect of continuous monitoring.

Despite these limitations, the evidence indicates that CGM provides clinically relevant information beyond HbA1c and can improve metabolic control and hypoglycemia detection in pediatric T1D. Its benefits are greatest when the device is used consistently, accompanied by appropriate education, and integrated into individualized insulin management. Future studies should apply standardized CGM outcome definitions, report sensor adherence and local adverse events systematically, and include longer follow-up periods. Greater attention should also be given to age-specific usability, caregiver burden, socioeconomic barriers, and equitable access to newer technologies. These factors will determine whether the efficacy observed in controlled studies can be translated into sustained benefits in routine pediatric diabetes care.

5. Conclusions

Continuous glucose monitoring represents a valuable component of pediatric T1D management, providing clinically relevant information beyond HbA1c. Across the reviewed studies, CGM was associated with improvements in TIR, TBR, TAR, glycemic variability, and hypoglycemia detection, although reductions in HbA1c were less consistent. The most favorable metabolic outcomes were observed with regular sensor use, in patients with poorer baseline glycemic control, and when CGM was integrated with automated or closed-loop insulin delivery.

Technological advances, including factory calibration, longer sensor wear, configurable alarms, remote data sharing, and integration with insulin pumps, have improved the usability and therapeutic potential of CGM. The systems demonstrated a generally favorable safety profile, with severe hypoglycemia and DKA occurring infrequently. CGM also facilitated the detection of nocturnal and asymptomatic hypoglycemia. Patient and caregiver satisfaction was generally high, although skin reactions, sensor discomfort, alarm burden, connectivity problems, and device discontinuation remained relevant limitations.

Overall, the clinical effectiveness of CGM depends not only on device accuracy but also on sustained use, appropriate education, family engagement, and the ability to translate glucose data into therapeutic

decisions. Future studies should use standardized CGM outcomes, provide longer follow-up, and systematically assess adherence, adverse events, quality of life, caregiver burden, and barriers to equitable access. Such an approach will allow the benefits demonstrated in clinical studies to be translated more effectively into routine pediatric diabetes care.

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