

# Optimizing Glycemic Outcomes for Children with Type 1 Diabetes

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## KEYWORDS

• Type 1 diabetes mellitus • Technology • Psychosocial • Education

## KEY POINTS

- Children with type 1 diabetes mellitus require psychosocial support and access to technologies to achieve glycemic targets.
- Multidisciplinary care is crucial for the prevention of acute complications as well as long-term macrovascular and microvascular complications.
- Continued quality improvement initiatives are needed to enhance diabetes technology uptake, improve education, and address psychosocial needs.

## INTRODUCTION

Type 1 diabetes mellitus (T1D) is an autoimmune disease characterized by the progressive irreversible loss of pancreatic  $\beta$ -cell function resulting in insulin deficiency. The estimated number of new T1D cases in individuals aged 0 to 19 years increased from 128,900 to 149,500 globally from 2019 to 2021.<sup>1</sup> Because of near-total insulin deficiency, affected children are dependent on lifelong exogenous insulin. Changes in physical growth, neurocognitive development, and pubertal maturation are only some of the challenges to achieving adequate glycemic stability during childhood and adolescence. To optimize glycemic outcomes in children with T1D, a comprehensive approach is crucial ([Fig. 1](#)).

## DEFINING GLYCEMIC OUTCOMES

There are multiple metrics to evaluate glycemic outcomes, including hemoglobin A1c (HbA1c), percentage of time in range (TIR) of blood gluceses, and frequency of acute and chronic diabetes-related complications. The American Diabetes Association (ADA) recommends assessing glycemic status at least biannually in patients who

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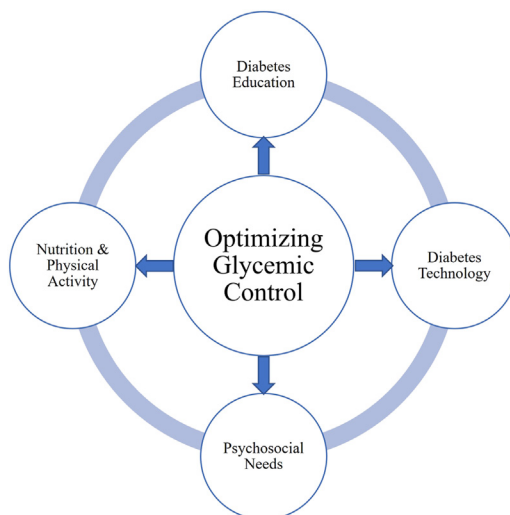
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**Fig. 1.** Approaches to optimizing glycemic control.

meet glycemic goals, and at least quarterly in patients who do not meet treatment goals or whose treatment regimen was recently changed.<sup>2</sup>

### ***Hemoglobin A1c***

HbA1c is a measure of hemoglobin glycation and approximates mean glucose levels during the past 3 months. HbA1c can be used as a marker for glycemic goal; however, there are limitations to its use. Conditions influencing red blood cell turnover (such as thalassemia) may result in a discrepancy between a patient's HbA1c result and actual mean glucose levels.<sup>3</sup> Additionally, HbA1c does not provide data on acute hypoglycemic or hyperglycemic events or measure glycemic variability. Therefore, using HbA1c in conjunction with blood glucose monitoring can enhance glycemic management.

The most recent ADA guidelines recommend HbA1c goals to be individualized but a glycemic target of HbA1c less than 7% is considered appropriate for most children and adolescents with T1D.<sup>4</sup> The issue remains that only a minority of children achieve this goal. The T1D Exchange Quality Improvement Collaborative (T1DX-QI) is a multi-center learning health system in the United States that aims to improve T1D care through shared learning.<sup>5</sup> Among the diabetes clinics participating in the T1DX-QI, only 23% of adults and 18% of children with T1D had a HbA1c less than 7% from 2017 to 2022.<sup>6,7</sup> A higher HbA1c target may be more appropriate in those with hypoglycemia unawareness, history of severe hypoglycemia, inability to routinely check blood glucoses, or limited access to diabetes technology.<sup>8</sup>

### ***Glucose Monitoring***

Glucose monitoring is key to achieving target glucose range, whether through finger stick blood samples or continuous glucose monitoring (CGM). Children with T1D should monitor glucose levels 6 to 10 times daily including before consuming meals and carbohydrate-containing snacks, at bedtime, and as needed for safety.<sup>4</sup> CGM provides data on TIR, defined as the percentage of time a patient's blood glucoses are between 70 and 180 mg/dL. TIR aids providers in fine-tuning insulin dose adjustments and correlates well with HbA1c.<sup>8</sup> It is recommended for greater than 70% of

daily readings to be in TIR, less than 4% of readings to be less than 70 mg/dL (defined as time below range), and less than 25% of readings to be greater than 180 mg/dL (defined as time above range).<sup>9</sup>

### ***Acute Diabetes Complications***

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Acute diabetes complications include hypoglycemia and diabetes ketoacidosis (DKA). Hypoglycemia, defined as blood glucose less than 70 mg/dL, is the limiting variable with fine tuning doses for maintaining TIR. Symptoms include confusion, hunger, irritability, and tremor. Patients with T1D may have a blunted counterregulatory response or reduced autonomic response to hypoglycemia and experience hypoglycemia unawareness, placing them at risk for loss of consciousness, seizure, or death. Young children or those with conditions affecting neurocognitive ability are particularly at a higher risk because they may not be able to recognize or communicate these symptoms.

### ***Chronic Diabetes Complications***

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Tight glycemic management in T1D delays the onset and progression of macrovascular and microvascular complications. The Diabetes Control and Complications Trial (DCCT), a prospective randomized controlled trial, compared intensive versus conventional diabetes treatment at the time of the study. Intensive treatment included insulin delivery with a pump or 3 or more insulin injections daily with self-monitoring of blood glucose at least 4 times per day, whereas conventional treatment consisted of 1 or 2 injections of insulin per day with daily self-monitoring of urine or blood glucose. The DCCT demonstrated that intensive glycemic control was associated with 39% to 76% reduction in onset and progression of microvascular complications and requirement for future ocular surgeries.<sup>10,11</sup> The DCCT also demonstrated a 41% reduction in all major cardiovascular and peripheral vascular events with intensive control, although not statistically significant.<sup>10</sup> Compared with patients in the conventional arm, those in the intensive arm had a 57% reduction in the risk of nonfatal myocardial infarctions, strokes, or cardiovascular death in a 9-year post-DCCT follow-up study.<sup>12</sup> As diabetes predisposes to accelerated arteriosclerosis, optimizing diabetes control as early in childhood can minimize these future events.<sup>4</sup>

## **APPROACH TO OPTIMIZING GLYCEMIC OUTCOMES: DIABETES EDUCATION**

Quality structured diabetes education is crucial to the success of diabetes management. The education should optimize the patient and family's understanding of the condition and its treatment, assist with adjustment to living with the new diagnosis, and gradually empower the patient and family in promoting self-management.<sup>13</sup> It should be adapted to each patient's age and development as well as the family's learning style, existing knowledge, and goals. For people living in remote areas with minimal access to professional education locally, telemedicine is an alternative medium to provide education. Web-based educational resources can be a useful supplementation, especially those designed by manufacturing companies for device-specific patient education.

At the time of diagnosis, emotional stress can affect the patient and families' ability to learn and retain new skills. Therefore, emphasis should be placed on acquiring basic skills required to safely manage diabetes at home. Families should be provided with educational materials (ie, books, booklets, and smart phone applications) in the appropriate language and literacy level. At the follow-up visits, education should be reinforced and expanded.

A multidisciplinary team of health-care professionals including a pediatric endocrinologist, certified diabetes care and education specialist, nutritionist, psychologist, and social worker should deliver ongoing education. The team should have access to the latest advances in insulin therapy, diabetes technologies, and educational methods. Specialized diabetes centers should support professional education, which in-turn will improve the quality of diabetes education and standard of care delivered to patients.<sup>14</sup>

As many children spend the majority of their time in daycare programs or schools, child care and school personnel should be equipped with appropriate training and supplies to care for children with T1D, including the ability to support children using diabetes technology.<sup>4,15</sup> Increased sensitivity and inclusion surrounding special occasions, such as celebrations or field trips, are necessary so that these children can participate in school activities in an equitable manner.<sup>15</sup>

### **APPROACH TO OPTIMIZING GLYCEMIC OUTCOMES: NUTRITION AND PHYSICAL ACTIVITY**

Nutrition therapy is an integral component to managing T1D.<sup>4</sup> Education should be initiated at diagnosis and reinforced at frequent intervals; it should include reading nutrition facts labels, carbohydrate counting, and balancing fat, protein, and carbohydrate consumption. Frequent assessments of nutrition and caloric intake by an experienced nutritionist are crucial to balance cardiovascular disease risk factors, weight status, and increased needs with growth and development. Nutrition counseling should be individualized and account for a multitude of factors including the child's food preference, the family's religious or cultural influences, and the family's finances and level of food security.

The American Academic of Pediatrics recommends for all youth at least 60 minutes daily of age-appropriate moderate-to-vigorous intensity physical activity.<sup>16</sup> Children with T1D require glucose monitoring before, during, and after physical activity and strategies should be developed to prevent hypoglycemia and hyperglycemia. Such strategies may include reducing basal insulin doses or using "exercise/activity mode" on an insulin pump as well as consuming complex carbohydrates before and/or after exercise.<sup>4</sup> Children with marked hyperglycemia (glucose level  $\geq 350$  mg/dL), moderate-to-large urine ketones, and/or  $\beta$ -hydroxybutyrate greater than 1.5 mmol/L should postpone intense activity because exercise can worsen these conditions.

### **APPROACH TO OPTIMIZING GLYCEMIC OUTCOMES: DIABETES TECHNOLOGY**

Initial management of T1D includes self-monitoring of blood glucose several times daily along with exogenous insulin delivery. Insulin preparations include analogs that are short acting (human regular insulin), rapid acting (insulin lispro, insulin aspart, and insulin glulisine), ultrarapid acting (faster insulin aspart, insulin lispro-aabc, and inhaled human insulin), intermediate acting (neutral protamine hagedorn insulin [NPH] insulin), and long acting (insulin glargine, insulin detemir, and insulin degludec).<sup>17</sup> Advances in diabetes technology in the past few decades include CGM and devices that automate some insulin delivery. They should be offered to all children with T1D who are able to use the devices safely by themselves or with the support and/or supervision of a caregiver. The decision of which device to use should be made according to the child and family's individual circumstances and preferences, in addition to the clinicians' assessment.<sup>4</sup>

#### ***Continuous Glucose Monitoring***

Although glucose meters measure glucose concentration from capillary blood, CGM devices are inserted into the subcutaneous fat and interstitial fluid is read via a small

disposable glucose oxidase-coated electrode. The glucose in the interstitial fluid reacts with the glucose oxidase to generate hydrogen peroxide, resulting in an electrical current that is sent to a transmitter and translated to an estimate of blood glucose concentration.<sup>18</sup> The transmitter then relays the values to a receiver, other mobile device, and/or an insulin pump.<sup>19</sup> CGM provides near-immediate feedback on glycemic excursions and patterns, which affects insulin management and lifestyle modifications.

CGM use has shown significant benefits to achieving glycemic control. Lower mean HbA1c has been observed in youth and young adult CGM users compared with nonusers, regardless of insulin administration method.<sup>20,21</sup> A clinical trial randomizing adolescents and young adults with T1D to CGM or standard blood glucose meter use for 26 weeks showed a statistically significant improvement in HbA1c in CGM users.<sup>22</sup> Rates of severe hypoglycemia and DKA are also lower in CGM users compared with nonusers.<sup>23</sup>

Toddlers and preschool children tend to have unpredictable eating patterns and variable physical activity levels, making T1D care in this age group particularly challenging.<sup>24</sup> Additionally, they have wide glucose fluctuations and limited ability to identify symptoms of hypoglycemia or hyperglycemia.<sup>25</sup> CGM use in these children identifies glycemic patterns, decreases parental worry, increases parental confidence about child safety, and promotes other caregivers' involvement by allowing remote monitoring functionality.<sup>26</sup> Parents can also use CGM data retrospectively to improve their understanding of variables that may influence glucose levels, including time of day and types of food or physical activity.<sup>26</sup> Consistent CGM use in a 6-month randomized controlled trial of children aged less than 8 years with T1D did not show improvements in TIR compared with blood glucose meter use; however, the number of hypoglycemic events and amount of glucose variability were reduced in CGM users.<sup>27</sup>

### ***Smart Insulin Pens***

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Smart insulin pens (SIPs) have a memory function that records the date, time, and amount of insulin administered. This record can be combined with CGM data and viewed by providers to enhance diabetes care.<sup>19</sup> SIP can calculate insulin doses if provided with blood glucose value and grams of carbohydrates being consumed, thereby having the potential to improve medication adherence. SIP can benefit young children by keeping track of when the last insulin dose was administered, which is helpful if there are multiple caregivers and potential gaps in communication. They can also benefit adolescents by increasing engagement and help track dose administration. In a one-arm prospective observational study of children with T1D using CGM in conjunction with SIPs for at least 12 months, the number of hypoglycemic events was reduced from baseline to follow-up.<sup>28</sup> Barriers to successful SIP use include lack of provider awareness and training and lack of patient education on SIP use.<sup>29</sup> Therefore, initiatives are needed to address these barriers while emphasizing the benefits of SIP use.

### ***Insulin Pumps***

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Insulin delivery has changed dramatically during the past several decades, from syringes, pens, and open-loop pumps to now hybrid closed-loop pump systems (HCLS).<sup>19,30,31</sup> Continuous subcutaneous insulin infusion pumps infuse a rapid-acting insulin analog through a catheter at basal rates and additional bolus doses for hyperglycemia correction and carbohydrate coverage with preprogrammed correction factors and carbohydrate ratios.<sup>19</sup> The pump can be programmed to deliver variable basal amounts throughout the day, and multiple profiles can be established for different circumstances, including illness, menstruation, and physical activity. In

comparison to a multiple daily injection regimen, insulin pump therapy in children has been associated with improved HbA1c and lower risks of severe hypoglycemia and DKA, with greater improvements in those with concomitant CGM use than in nonusers.<sup>32,33</sup>

Closed-loop insulin delivery links CGM data with an insulin pump to automate insulin delivery. Initial models of this technology suspend insulin delivery when sensor glucose level reaches or is predicted to reach a preset low threshold, called sensor-augmented pump therapy with predictive low-glucose suspend function.<sup>19</sup> Newer HCLS models allow for real-time adjustments in basal infusion rates in response to declining or increasing glucose levels.<sup>18</sup> HCLS has been associated with lower HbA1c and higher TIR, and the degree of HbA1c improvement is greater than that seen with sensor-augmented pump therapy, CGM, and insulin pump use without a closed-loop algorithm, or multiple daily injection regimen.<sup>21,34,35</sup>

In 2 randomized trials of young children with T1D who received HCLS compared with sensor-augmented pump therapy, HCLS resulted in higher TIR and lower HbA1c.<sup>36,37</sup> For example, in the HCLS group, the mean TIR increased from 56.7% at baseline to 69.3% during the 13-week follow-up period, compared with the standard care group, which included a CGM with either an insulin pump or multiple daily injections, of 54.9% at baseline to 55.9% at follow-up; the mean adjusted difference was 12.4% points, equivalent to approximately 3 hours daily.<sup>37</sup> HCLS may be especially beneficial for young children whose families may permit hyperglycemia for fear of hypoglycemia.<sup>38</sup> By reducing hyperglycemia permissive behaviors, young children can readily achieve target glycemic goals.

Although insulin pump therapy, and more recently HCLS, improves glycemic outcomes in children with T1D, it is important to consider the feasibility of using them and their psychosocial influence on patients and their families. Significant resources are required for educating families on ways to optimize the usage of pump therapy. Unsuspected pump failure may result in DKA, making it imperative that patients and their families learn how to prevent, recognize, and manage pump failures. Current studies report generally positive feedback on HCLS, including improved quality of life, sleep, confidence, and reduced anxiety about hypoglycemia and hyperglycemia.<sup>35,39</sup> Nevertheless, it is important to recognize the challenges of HCLS use in children, including alarm fatigue from frequent alarms, calibration difficulties, and wearing devices that are challenging to conceal from peers if they do not want to disclose their diagnosis.<sup>40</sup>

## APPROACH TO OPTIMIZING GLYCEMIC OUTCOMES: PSYCHOSOCIAL NEEDS

A multidisciplinary team should provide support at the time of diagnosis of T1D and regular intervals thereafter in a developmentally appropriate and culturally sensitive manner.<sup>4</sup> The support should address social determinants of health (SDOH) and emotional, behavioral, or psychosocial factors that may pose a barrier to implementing treatment plans.<sup>41</sup> Screening for families' SDOH at routine diabetes appointments can identify unemployment and food or housing insecurity that may take precedence over intensive diabetes management, and these families should receive additional care from community health workers.

Family involvement is crucial in optimizing glycemic control throughout childhood and adolescence. Families may experience distress related to the burden of managing diabetes, including worry about hypoglycemia, future complications, and interrupted sleep.<sup>42</sup> Parental psychosocial functioning and adjustment may indirectly affect children's T1D outcomes.<sup>43</sup> Incorporating social support and building parental diabetes

self-efficacy throughout all visits may build parental resilience and serve as a protective factor against diabetes-related distress.<sup>27,44</sup>

As the child develops and desires independence in their diabetes care, the multidisciplinary team must ensure appropriate transfer of self-management responsibilities and reinforce that the youth will still need supervision. Premature transfer of responsibilities or lack of adult supervision can result in suboptimal management, diabetes burnout, and worsening of glycemic outcomes.<sup>4</sup> The need for increasing autonomy in diabetes self-management along with the psychosocial changes that happen in adolescence can pose challenges to achieving optimal glycemic management.<sup>15</sup> Shared decision-making with adolescents, preventing diabetes-related family conflict, and providing adolescents time alone with providers may increase engagement and adoption of the management plan.

Depressive symptoms often coexist with T1D and are associated with an increased risk for elevated HbA1c and DKA.<sup>45</sup> Children and adolescents with T1D have a 2 to 3-fold greater prevalence of diabetes compared with peers without diabetes.<sup>46</sup> Furthermore, compared with children with HbA1c less than 7%, those with HbA1c greater than 7% were more likely to screen positive for depression or anxiety.<sup>7</sup> The perpetual cycle between mental health issues influencing diabetes management and vice-versa is important to recognize. It is imperative to routinely assess psychosocial health with tools such as the PHQ-2, generally starting at 7 to 8 years of age, and to refer to a mental health professional as soon as indicated.<sup>4</sup> If signs of disordered or disrupted eating are noted, the motivation behind these behaviors should be further explored to assess for mental distress or an underlying eating disorder.<sup>47</sup>

### ***Racial, Ethnic, and Socioeconomic Disparities***

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Multiple studies have demonstrated racial/ethnic disparities in the health outcomes of children with T1D, with patients from groups that have been marginalized having a higher HbA1c and more acute complications.<sup>48,49</sup> Among children in the T1DX-QI with HbA1c less than 7%, 9% were non-Hispanic Black and 9% were Hispanic compared with 66% non-Hispanic White.<sup>7</sup> Compared with other racial/ethnic groups, non-Hispanic Black individuals had the highest rates of DKA before and during the coronavirus disease 2019 (COVID-19) pandemic; additionally, they were almost 4 times more likely to present in DKA during the COVID-19 pandemic compared with non-Hispanic Whites even after adjusting for sex, age, insurance status, and HbA1c.<sup>50,51</sup>

CGM and insulin pumps should be accessible to all patients with T1D as part of routine diabetes care.<sup>21,23,34</sup> In the T1DX-QI Collaborative, CGM use was highest in non-Hispanic White patients (50%), compared with Hispanic patients (38%) and non-Hispanic Black patients (18%), and these disparities existed even when stratifying by insurance type.<sup>23</sup> The same disparities were seen in HCLS use.<sup>34</sup> In a single-center cohort of children with T1D, non-Hispanic White patients were more likely to use both a CGM and insulin pump compared with no technology use; in contrast, Hispanic and non-Hispanic Black patients were more likely to not use technology.<sup>21</sup> Language differences may pose a barrier to managing T1D through technology use. Spanish-speaking patients in one study were found to have lower rates of CGM and insulin pump use than English-speaking patients, despite the center having a culturally sensitive Spanish language clinic.<sup>21</sup>

Disparities in diabetes technology utilization also exist across socioeconomic status (SES). Patients with private insurance are more likely to use CGM and insulin pumps than those with public insurance.<sup>21,23</sup> Using parental education level, insurance type, and annual income to create a composite SES score, patients with the lowest SES quintile had the lowest rates of CGM and pump use and highest HbA1c when compared with

the other quintiles.<sup>52</sup> Even after adjusting for SES, insulin pump use was higher in non-Hispanic White children than in Hispanic and non-Hispanic Black children.<sup>53</sup>

The inequity in technology use by race/ethnicity may be contributing to the racial/ethnic disparities seen in glycemic outcomes. Additionally, the providers' perception of family's competence and implicit biases need to be studied so that these do not pose as additional barriers in equitable technology use.<sup>54</sup>

## SUMMARY

Despite technological advances that have enhanced the capability to optimize glycemic management, many children with T1D are unable to meet the recommendations because of a multitude of barriers in SDOH, education, technology access, and psychosocial support. This has led to quality improvement initiatives such as the T1DX-QI, which focuses on areas such as care delivery, self-management, and psychosocial support.<sup>55,56</sup> One initiative increased CGM use in 12 to 26-year-old patients with T1D from 34% to 55% during 19 to 22 months using interventions such as coaching patients, training clinical teams, and provider engagement in advocacy efforts to promote CGM coverage by their state's Medicaid program.<sup>57</sup> Another initiative increased insulin pump adoption in 12 to 26-year-old patients with T1D by 13% by increasing in-person and telehealth technology education and improving clinic staff knowledge.<sup>58</sup> Although continued efforts are needed to develop processes that improve T1D care for all patients, emphasis needs to be placed on initiatives that eliminate racial, ethnic, and socioeconomic disparities.<sup>59,60</sup> Strategies are also needed to ensure equitable availability of insulin and technologies.

Achieving target blood glucose levels in children with T1D requires addressing the medical and psychosocial aspects of T1D. Additional quality improvement study is needed to reduce gaps in care delivery, psychosocial support, and health equity, such that diabetes care and quality of life can be improved for all children with T1D.

## CLINICS CARE POINTS

- A multidisciplinary approach is necessary to achieve glycemic target in children with T1D.
- Hemoglobin A1c and TIR at goal reduce the risk of acute and chronic complications of diabetes.
- Technologies that have aided the management of T1D in children include continuous glucose monitors, SIPs, and insulin pumps.
- Use of diabetes technology in children with T1D has resulted in lower HbA1c and improved quality of life.
- Ongoing diabetes education, family support, and identification of SDOH are important to ensure adherence to diabetes treatment plans and reduction of barriers to glycemic targets.

## DISCLOSURE

The authors have no commercial or financial conflicts of interest.

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