Technology for Augmenting Type 1 Diabetes Mellitus Management

Michelle Condren, PharmD; Samie Sabet, PharmD; Laura J. Chalmers, MD; Taylor Saley, MD, MPH; and Jenna Hopwood, PharmD

Type 1 diabetes mellitus has witnessed significant progress in its management over the past several decades. This review highlights technologic advancements in type 1 diabetes management. Continuous glucose monitoring systems are now available at various functionality and cost levels, addressing diverse patient needs, including a recently US Food and Drug Administration (FDA)–approved implantable continuous glucose monitoring system (CGMS). Another dimension to these state-of-the-art technologies is CGMS and insulin pump integration. These integrations have allowed for CGMS-based adjustments to basal insulin delivery rates and suspension of insulin delivery when a low blood glucose event is predicted. This review also includes a brief discussion of upcoming technologies such as patch-based CGMS and insulin-glucagon dual-hormonal delivery.

ABBREVIATIONS CGMS, continuous glucose monitoring system; CSII, continuous subcutaneous insulin infusion; FDA, US Food and Drug Administration; FSBS, finger stick blood sugar; Hgb A1c, hemoglobin A1c; MARD, mean absolute relative difference; MDI, multiple daily insulin injection; PDM, Personal Diabetes Manager; T1DM, type 1 diabetes

KEYWORDS continuous glucose monitoring; continuous subcutaneous infusion; glucagon; insulin; insulin infusion system; type 1 diabetes mellitus

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Introduction

According to the T1D Exchange clinic registry, a cohort of more than 32,000 individuals with type 1 diabetes, nearly three-fourths of pediatric patients fail to achieve target glycemic control, defined as a hemoglobin A1c (HgbA1c) < 7.5%, as set by the American Diabetes Association and the International Society for Pediatric and Adolescent Diabetes.¹ Frequently cited barriers to pediatric glycemic control include unpredictable intake, permissive hyperglycemia due to fear of hypoglycemic events, time and emotional burden of frequent monitoring, and dosage changes.² This article summarizes advances in technology developed with the goal of improving both blood sugar control and quality of life for children with type 1 diabetes (T1DM).

Advances in Glucose Monitoring

Continuous Glucose Monitoring Overview. Glucose monitoring first began in the mid-1900s with simple, though imprecise, urine testing. The decades since have seen an exponential increase in the understanding of diabetes pathophysiology and complications with corresponding advances in monitoring technology. Each new monitoring system sought to improve measurement accuracy and overall glycemic control, while minimizing barriers to use and disease complications.

Continuous glucose monitoring systems (CGMSs) are the most recent technologic development.

CGMS uses interstitial glucose monitoring to display glucose concentrations frequently throughout the day. This regular surveillance allows for determinations of glucose trends and immediate feedback while omitting numerous daily finger stick blood glucose tests. There is a strong correlation between glucose monitoring frequency and lower HgbA1c concentrations.³ Numerous studies have demonstrated improved HgbA1c without increased incidence of hypoglycemia in patients using CGMS, especially with consistent use.^{4–6} The immediate feedback and glucose trending provided by CGMS offer marked advantages in early intervention and limitation of glycemic excursions, as compared with traditional finger stick testing. Additionally, numerous device models allow for data display on a remote receiver or even transmission to cellular phones. The historic recall features and graphical trends in CGMS provide advantages in overall disease management as compared with traditional finger stick blood glucose measurements. Finally, CGMS address the psychological burden imparted by vigilant management, with parents of children using CGMS reporting decreased overall stress and worry about their child's health.² However, criticism of interstitial sampling accuracy limited widespread use until the advent of next-generation devices to be discussed in this article.

In light of a growing body of evidence supporting the use of CGMS and a recent 2- to 3-fold increase in device use amongst pediatric populations, professional societies have published consensus guidelines on the use of CGMS in T1DM therapy.¹ The Advanced Technologies and Treatment for Diabetes Congress advocates for the use of CGM in conjunction with HgbA1c to assess glycemic status and adjust therapy in all patients with T1DM.⁷ They also call for all devices to report 14 metrics to assess glycemic control, including mean glucose, percentage of time <54 mg/dL, percentage of time 54–69 mg/dL, percentage of time in target range of 70–180 mg/dL (allowing for customization of upper limit), percentage of time >180 mg/dL, percentage of time >250 mg/dL, glycemic variability, and estimated HgbA1c along with other metrics to summarize data completeness and patterns throughout the day.⁷ Similarly, the American Association of Clinical Endocrinologists and American College of Endocrinology support the use of CGMS in children and adults with T1DM, as technological advances have improved device accuracy and reliability. These newer devices may help to reduce the overall cost of diabetes care by alerting patients to potential glucose deviations.⁸ Table 1 summarizes available CGMSs.⁹

Office-Based CGMS. The FreeStyle Libre Pro (Abbott Diabetes Care Inc, Alameda, CA) and the Dexcom G4 PLATINUM Professional CGMS (Dexcom Inc, San Diego, CA) are CGMSs owned by and used in clinicians' offices. A sensor is placed on the patient during an office visit and worn for 7 to 14 days. While in place, the sensor measures glucose in the subcutaneous tissue every 5 minutes. The sensor is then returned to the clinician who reviews the data. These devices allow a broader view of glucose variability throughout the day and can help fine-tune insulin doses without introducing new technologies into the patient's daily routine. It is also useful for documenting hypoglycemia unawareness, which can help justify the need for at-home CGMS to insurance companies.

Home-Based CGMS. Flash Glucose Monitoring System. FreeStyle Libre (Abbott Diabetes Care Inc., Alameda, CA) was marketed to replace finger stick blood sugar (FSBS) testing in December 2017. This system does not require FSBS calibration and is US Food and Drug Administration (FDA) approved for individuals 18 years of age and older, as long as they are not pregnant, critically ill, or on dialysis. One study has shown the FreeStyle Libre system to be safe and accurate in children 4 to 17 years of age.¹⁰ This is an at-home device available for purchase in local pharmacies. It consists of a sensor placed on the upper arm and a separate scanning device that can also be used as a glucose meter, reading both the sensor's blood glucose values and, if needed, FSBS. Given the infrequent need for FSBS testing, foil-wrapped glucometer strips are sold separately. The sensor is worn for up to

10 days and uses a <0.4-mm filament inserted into the skin of the upper arm to measure interstitial glucose. Once inserted, the sensor must be activated with the scanner and requires 12 hours to warm up before CGMS values are available. After calibration, the FreeStyle Libre can provide glucose values up to every minute and stores readings every 15 minutes. There is also a 10- to 15-minute time delay between the measured interstitial glucose reading and the capillary glucose obtained by FSBS testing. Calibration is not routinely needed, but it is recommended to check an FSBS if the patient's clinical symptoms differ from the scanner value or if the system predicts that the CGMS reading will be <70 mg/dL in the next 10 to 15 minutes. A notable difference between this device and other CGMSs is the absence of alerts to changes in blood glucose. Instead, the user can only see blood glucose values or trends when they scan the sensor.

Abbott Diabetes Care quotes a mean absolute relative difference (MARD) from FSBS of 9.7% over 10 days. The available pediatric study demonstrated a MARD from FSBS of 13.9%.¹⁰ While controversy exists about what constitutes an acceptable MARD, limited data suggest that if the MARD is ≤10%, insulin doses would not be affected by the difference between the FSBS and CGMS value.⁷ The device's documented MARD allowed for FDA approval of insulin dosing based solely on the scanner's glucose value, as opposed to confirmation FSBS required of older models. The automatic input target glucose guidelines are 70 to 180 mg/dL. Trend arrows displayed on the scanner provide an indication as to the direction of glucose change, but again do not provide real-time user alerts. Straight up or down arrows indicate a >2 mg/dL per minute glucose change, vector up or down arrows indicate a 1 to 2 mg/dL per minute glucose change, and horizontal arrows a <1 mg/dL per minute glucose change. Clinical studies have shown a 38% to 50% decrease in hypoglycemic events with use of the FreeStyle Libre as compared with FSBS testing alone.^{11,12}

The FreeStyle Libre system can be scanned at a distance of 1 to 4 cm from the sensor and allows data to be downloaded in the clinician's office. The sensor must be removed before magnetic resonance imaging, computed tomography scan, X-ray, or diathermy treatment.

In August 2018, the Freestyle Libre 14 Day (Abbott Diabetes Care Inc., Alameda, CA) was FDA approved; it offers a 14-day sensor wear time and only requires 1 hour to warm-up and begin reading glucose concentrations after sensor activation. In November 2018, the company launched a smartphone application that allows the user's phone to replace the traditional reader, providing an advantage of decreased device burden of having the separate required reader.

Dexcom G5. Dexcom G5 Mobile CGMS (Dexcom Inc, San Diego, CA) is FDA approved for individuals 2 years

Table 1. Available Stand-Alone Continuous Glucose Monitor Comparison ⁹						
Product	Warm-up Time	Calibration Required	Affected by Acetaminophen	FDA-Approved Age	Sensor Duration	Features
FreeStyle Libre (Abbott Diabetes Care Inc, Alameda, CA)	12 hr	No	No	≥18 yr	10 days	<ul style="list-style-type: none">• Must be scanned by reader to see blood glucose value and trend• Includes built-in blood glucose meter• Must be removed before MRI, CT scans• Can be obtained at pharmacies• Lower cost alternative at approximately \$120 start-up cost and \$100 per month in sensors
FreeStyle Libre 14 Day System (Abbott Diabetes Care Inc, Alameda, CA)	1 hr	No	No	≥18 yr	14 days	<ul style="list-style-type: none">• Must be scanned by reader to see blood glucose value and trend• In-phone application can be used as a reader• Includes built-in blood glucose meter• Must be removed before MRI, CT scans• Can be obtained at pharmacies• Lower cost alternative at approximately \$120 start-up cost and \$50 per month in sensors
Dexcom G5 Mobile (Dexcom Inc, San Diego, CA)	2 hr	Yes. Every 12 hr when blood glucose is between 40 and 400 mg/dL	Yes	≥2 yr	7 days	<ul style="list-style-type: none">• Alerts for customizable high or low blood glucose values. Also shows trends for rate of rise or fall in blood glucose• Data continuously available on the receiver or smart device• Compatible with Tandem T:slim X2 pump• Transmitter attached to sensor is replaced every 3 months• Cost approximately \$1800 start-up and \$300 per month in sensors
Dexcom G6 (Dexcom Inc, San Diego, CA)	2 hr	No	No	≥2 yr	10 days	<ul style="list-style-type: none">• Easier sensor insertion and smaller profile• Data continuously available on the receiver or a smart device• Alerts for customizable high or low blood glucose values. Also shows trends for rate of rise or fall in blood glucose• Transmitter attached to sensor is replaced every 3 months• Cost approximately \$1800 start-up and \$300 per month in sensors

CT, computed tomography; MRI, magnetic resonance imaging

of age and older. This system can send data wirelessly to a receiver or compatible smart device to display real-time glucose data. The sensor and receiver are paired before placing the sensor on the body. Once the sensor is placed on either the stomach (adult and child) or lower back (child), the user activates the sensor with the receiver. The sensor is recommended to be placed 3 inches from the site of insulin injections or pump insertion. This sensor has a life of 7 days and can be worn in the shower. The t:slim X2 Insulin Pump (Tandem Diabetes Care, San Diego, CA) can be integrated with Dexcom G5 CGMS to show user data on the pump screen. Currently this system can only be paired with 1 device (smart phone or insulin pump). Users and clinicians can also view the data to guide diabetes management through Dexcom CLARITY Diabetes Management Software (Dexcom Inc) or on the Clarity app (Dexcom Inc).

There is a 2-hour warm-up period during which time there are no CGMS values given and the receiver must stay within 20 feet of the sensor. It provides an interstitial glucose value every 5 minutes for a total of 288 in a 24-hour period. The receiver will alert the user after the 2-hour warm-up and requires 2 back-to-back FSBS readings for initial calibration. To maintain accuracy, the system requires calibration at least once every 12 hours and the FSBS value must be entered within 5 minutes. The FSBS value must be between 40 and 400 mg/dL for the system to accept it as a calibration. Of note, patients should be counseled not to rely on CGMS glucose readings if acetaminophen has been taken, as it will affect the accuracy of the readings.

When the system is calibrated appropriately, diabetes treatment decisions without confirmatory FSBS value are permitted. Designed to help avoid high and low glucose values, this system has customizable glycemic thresholds and alerts of up, down, and out-of-range trends. This system has proven to lower HgbA1c with an average reduction of 1.3% in patients with type 1 diabetes mellitus.⁶

Dexcom G6. Dexcom G6 CGMS (Dexcom Inc., San Diego, CA) was released in April 2018 and is approved for use in those 2 years and older. It offers improved size, easier insertion, and is the first CGMS that does not require FSBS calibration. This system comes with an easy-to-use auto-applicator, inserting the sensor-transmitter with the touch of a button. Once the sensor has been inserted into the skin, it may take up to 30 minutes for the sensor and receiver to pair. Once paired there is a 2-hour warm-up period before glucose values will be displayed from the sensor. The receiver device must stay within 20 feet of the transmitter during the warm-up period. Dexcom G6 CGMS does not require calibration or FSBS to make diabetes management decisions, but it is recommended to check an FSBS after treating a low blood glucose event if the user is still having hypoglycemia symptoms. Once inserted, the

system lasts for 10 days and is water resistant to a depth of 8 feet for a duration of 24 hours. The user may also take up to 1000 mg of acetaminophen every 6 hours and maintain accurate glucose readings.

Eversense CGMS. In June 2018, the FDA approved the Eversense CGMS (Senseonics, Germantown, MD) as the first implantable device for monitoring blood glucose control. Currently approved for use in adults only, the system consists of a sensor placed subcutaneously in the upper arm in the physician's office every 3 months. A transmitter is worn over the sensor to allow for communication with a mobile app. An additional development is the presence of vibration alerts at the sensor site on the body, potentially decreasing the risk for not hearing or feeling alerts from an external device. A 180-day version of this CGMS is available in Europe and the company is expected to seek FDA approval.

Advances in Insulin Pump Technology —

Insulin pump therapy has become commonplace in pediatric diabetes management. The decision to start insulin pump therapy is individualized on the basis of patient preference, need for flexibility in insulin dosing due to activity levels, and overall attention to self-care. Whether insulin pump therapy will improve blood glucose control or reduce complications has been the subject of many studies. A 2017 systematic review and meta-analysis of 25 randomized controlled trials comparing glycemic control between multiple daily insulin injections (MDIs) and continuous subcutaneous insulin infusion (CSII) found a statistically significant reduction in HgbA1c (mean difference 0.37%; 95% CI, 0.24–0.51) in children and adults using CSII.¹³ A subgroup analysis for children revealed that HgbA1c was reduced by 0.32% more in children who were treated with CSII than with MDIs.¹³ No significant differences in minor or severe hypoglycemic events were found between treatment groups nor was there a difference in time spent in hypoglycemia for adults or children.¹³ This meta-analysis¹³ included studies that used long-acting, rapid-acting, regular, and NPH insulin in the MDI treatment groups. This variability in dosing regimens, and inclusion of regular and NPH, limit generalizability owing to the current standard of care calling for the use of long-acting and rapid-acting insulins only.

Based on available studies, it cannot be concluded that insulin pump therapy improves outcomes when compared with MDI therapy. However, insulin pump technology has accelerated rapidly in recent years, with the approval of insulin pumps that automatically suspend when a blood sugar is low, integration with CGMS, and now adaptive pumps that automatically adjust insulin delivery on the basis of the blood sugar reading received from the CGMS. Table 2 summarizes available insulin pump systems, excluding those that are soon to be removed from the market.¹⁴ Newly available products are summarized below.

Table 2. Available Insulin Pump Comparison¹⁴

Product	Smallest Basal Increment	Smallest Bolus (Bolus Increment)	Features
OmniPod (Insulet Corporation, Boston, MA)	0.05 units/hr	0.05 units (0.1, 0.5, or 1 unit)	<ul style="list-style-type: none"> Only pump with no tubing. Insulin worn on a pod on the skin with wireless communication to PDM to control insulin delivery. Basal delivery in the absence of the PDM. Bolus doses must be programmed by the PDM. No CGM integration available.
MiniMed Paradigm Revel (Medtronic Diabetes, Minneapolis, MN)	0.025 units/hr up to 0.975 units, then 0.05 units/hr up to 9.95 units, 0.1 units/hr for ≥ 10 units	0.025 units (0.1 units)	<ul style="list-style-type: none"> Stand-alone pump with optional CGM integration. When combined with CGM, alerts user when blood glucose is rising or falling or meets a set high or low blood glucose limit. Pump data can be displayed on Apple or Android devices.
MiniMed 530G (Medtronic Diabetes, Minneapolis, MN)	0.025 units/hr up to 0.975 units, then 0.05 units/hr up to 9.95 units, 0.1 units/hr for ≥ 10 units	0.025 units (0.1 units)	<ul style="list-style-type: none"> When combined with the included CGM, insulin delivery stops for up to 2 hr if glucose reaches the low limit and the user does not respond to the low-glucose alarm. Alerts 30 min before reaching preselected upper or lower limit, based on rate of blood glucose change.
MiniMed 630G (Medtronic Diabetes, Minneapolis, MN)	0.025 units/hr up to 0.975 units, then 0.05 units/hr up to 9.95 units, 0.1 units/hr for ≥ 10 units	0.025 units (0.025 units)	<ul style="list-style-type: none"> When combined with the included CGM, insulin delivery stops for up to 2 hr if glucose reaches the low limit and the user does not respond to the low-glucose alarm. Alerts 30 min before reaching preselected upper or lower limit, based on rate of blood glucose change. Improved waterproof capability. Communicates with Contour Next Blood Glucose Meter. Improved full-color display.
MiniMed 670G (Medtronic Diabetes, Minneapolis, MN)	0.025 units/hr up to 0.975 units, then 0.05 units/hr up to 9.95 units, 0.1 units/hr for ≥ 10 units	0.025 units (0.025, 0.05, 0.1 units)	<ul style="list-style-type: none"> Hybrid closed-loop pump allows user to choose level of automation. Auto Mode feature adjusts basal insulin as based on CGM readings and recent insulin doses. Insulin delivery stops for up to 2 hr if glucose reaches the low limit and the user does not respond to the low-glucose alarm. Improved waterproof capability. Communicates with Contour Next Blood Glucose Meter. Improved full-color display.
T:fix Pump (Tandem Diabetes Care, San Diego, CA)	From 0.5 units, increments of 0.001 units	0.5 units (0.01 units)	<ul style="list-style-type: none"> No CGM integration available. Rechargeable battery via USB. Largest reservoir of available pumps (480 units). Touch screen display.
T:slim X2 Pump (Tandem Diabetes Care, San Diego, CA)	From 0.1 units, increments of 0.001 units	0.05 units (0.01 units)	<ul style="list-style-type: none"> Integrates with Dexcom G5 CGM. Rechargeable battery via USB. Touch screen display. Basal-IQ upgrade stops basal delivery when blood glucose is projected to be low in the next 30 min. Basal delivery resumes once glucose begins to rise. Basal-IQ upgrade integrates with Dexcom G6 CGM

CGM, continuous glucose monitoring; PDM, Personal Diabetes Manager

Medtronic MiniMed 670G. MiniMed 670G (Medtronic, Minneapolis, MN) with SmartGuard technology is the first available hybrid closed-loop CSII system. It is FDA approved for use in people with T1DM who are 14 years of age and older, with ongoing studies in children 2 to 13 years of age. This system communicates with an Enlite CGMS (Medtronic) provided with the pump and offers 3 operating modes: manual mode, suspend on low, and auto mode. Manual mode operates similarly to other available insulin pumps, using preprogrammed doses and boluses given by the patient as needed for carbohydrate intake or elevated blood glucose. Suspend on low stops insulin infusion 30 minutes before it predicts reaching the programmed low limit and restarts insulin infusion once the glucose concentration has recovered as based on the sensor glucose value. This helps to limit hypoglycemic events and the need for treatment, which can lead to rebound hyperglycemia.

Initially, the pump is worn in manual mode for a minimum of 1 week before starting auto mode. Auto mode allows the system to automatically change basal insulin every 5 minutes, based on incoming sensor readings, to achieve a target blood glucose concentration of 120 mg/dL. A temporary target (recommended 1 hour before, during, and after exercise) blood glucose value of 150 mg/dL can be set for up to 12 hours. Calibration of the system is recommended at least 3 to 4 times per day (fasting, dinner, and bedtime) but must be done at least every 12 hours. It is recommended that insulin-dosing decisions for carbohydrate intake only be made after confirmation by an FSBS. For the system to remain in auto mode and work accurately, insulin for carbohydrate intake must be given by bolus pre-meal. Insulin to carbohydrate ratio adjustments will be needed over the first 3 months owing to the responsiveness of basal insulin throughout the day.¹⁵

All FSBS values should be obtained from the meter designed to communicate with the pump. The system will change from auto mode to manual mode for various reasons, including calibration of system with FSBS needed or if the sensor is not communicating with the pump. If acetaminophen is taken, the user will need to switch the pump to manual mode because the sensor readings will not be reliable. Although waterproof, the sensor will not communicate with the pump through water so caution should be exercised with prolonged underwater activity, as safe basal dosing will only last for 90 minutes without sensor glucose readings.

Because auto mode basal insulin delivery is designed to adjust insulin needs during menses, lack of sleep, and periods of stress, and respond to real-time changes in blood glucose, it is expected to improve blood glucose-related outcomes. Results for the benefits of this system to date are encouraging with studies reporting decreases in HgbA1c of 0.5% to 0.75% over a 3-month period with additional documentation of increased percentage of time spent in target blood glucose range.^{15–17}

Tandem t:slim X2. The Tandem Diabetes Care introduced the first available touch screen technology in the smallest available pump. They are also unique in that they allow for software updates through syncing with home computers. The latest distinguishing feature arrived in July 2018, when Tandem Diabetes Care gained approval for the Tandem t:slim X2 with Basal-IQ technology (Tandem Diabetes Care). This collaboration represents the first integration with CGMS that does not require FSBS measurement to dose insulin by integrating with the Dexcom G6 CGMS. Throughout the day, the new Basal-IQ technology anticipates 30 minutes ahead as based on trends and suspends insulin in time of impending lows until the blood glucose begins rising again. Patients on a prior version of the t:slim pump will be able to download a software update to gain the functionality of Basal-IQ technology without the need to buy a new pump. The company is expected to release an upgrade in the near future that is more of a hybrid closed-loop system, responding to both high and low blood sugars.

Technology on the Horizon

SugarBeat (Nemauro Medical, Loughborough, United Kingdom) launched in the United Kingdom in 2018 and the company expected to apply for FDA approval in 2018 as well. This CGMS is a stick-on patch device that is worn for 24 hours and changed daily. It obtains glucose readings every 5 minutes and requires calibration with FSBS once a day. Studies in adults have resulted in similar reliability to previously mentioned CGMSs. If FDA approved, it would offer the first needle-free system.

The Omnipod Insulin Management System (Insulet Corporation, Boston, MA) offers a unique advantage of being a tubeless system whereby insulin doses are programmed and delivered by using a separate device called the Personal Diabetes Manager (PDM). In early 2019, Insulet will begin a limited market release of the Omnipod Dash PDM. This new system will allow Bluetooth integration with an iOS smartphone app to control insulin dosing from the phone without the need for a separate PDM. However, users have the choice to use the PDM if preferred, or in the event their mobile phone is not functional. Although it will not directly integrate with any CGMS for seamless communication, it will allow a joined display through the app to be able to see Dexcom CGMS and pump data side by side. The use of limited market release allows the company to ensure functionality in the home environment and make any needed upgrades before a full market release.

Bihormonal Artificial Pancreas. Simultaneous insulin and glucagon delivery, also known as bihormonal delivery, is a topic of current research. To date about 7 pediatric trials with a bihormonal feature in their designs have been completed with more ongoing. Some of these studies, while featuring bihormonal delivery, focused primarily on efficacy of “adaptive

meal-priming boluses” where the closed-loop system calculates mealtime boluses from the size (typical, more than usual, less than typical, or a small bite) and type (breakfast, lunch, dinner, snack) of the meals in addition to response to previous meal boluses.^{18–20} The studies conducted by Haidar and colleagues^{21–23} included 3 arms consisting of dual-hormone artificial pancreas, single-hormone artificial pancreas, and conventional insulin pump. These trials demonstrated that subjects in the dual-hormone artificial pancreas arm stayed in the target glucose range longer and experienced less hypoglycemia than those in conventional insulin pump and even single-hormone artificial pancreas arms, but the differences were not always statistically significant.^{21–23} Although the results of these studies do not suggest imminent approval and marketing of bi-hormonal delivery technologies, they do provide insight into closed-loop artificial pancreas systems.

Conclusions

The use of technology in diabetes management is increasing rapidly and is supported by the International Society of Pediatric and Adolescent Diabetes.²⁴ The potential for less finger sticks while getting more reliable data through continuous glucose monitoring is now a reality. Insulin pump systems with algorithms designed to decrease low and high blood sugars through integration with continuous glucose data offer the potential for increased safety and improved quality of life. Technology is at the forefront of innovations in diabetes management.

ARTICLE INFORMATION

Affiliations Department of Pediatrics (MC, SS, LJC, JH), The University of Oklahoma School of Community Medicine, Tulsa, Oklahoma; Children's Hospital of Los Angeles (TS), Los Angeles, California; College of Pharmacy (JH), The University of Oklahoma Health Science Center, Oklahoma City, Oklahoma

Correspondence Michelle Condren, PharmD;
michelle-condren@ouhsc.edu

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REFERENCES

1. Miller KM, Beck R, DeSalvo D, et al. Current state of type 1 diabetes treatment in the U.S.: updated data from the T1D Exchange clinic registry. *Diabetes Care*. 2015;38(6):971–978.
2. Erie E, Van Name MA, Weyman K, et al. Schooling diabetes: use of continuous glucose monitoring and remote monitors in the home and school settings. *Pediatr Diabetes*. 2018;19(1):92–97.
3. Miller KM, Beck RW, Bergenstal RM, et al. Evidence of a strong association between frequency of self-monitoring of blood glucose and hemoglobin A1c levels in T1D exchange clinic registry participants. *Diabetes Care*. 2013;36(7):2009–2014.
4. Beck RW, Buckingham B, Miller K, et al. Factors predictive of use and of benefit from continuous glucose monitoring in type 1 diabetes. *Diabetes Care*. 2009;32(11):1947–1953.
5. Beck RW, Hirsch IB, Laffel L, et al. The effect of continuous glucose monitoring in well-controlled type 1 diabetes. *Diabetes Care*. 2009;32(8):1378–1383.
6. Tamborlane WV, Beck RW, Bode BW, et al. Continuous glucose monitoring and intensive treatment of type 1 diabetes. *N Engl J Med*. 2008;359(14):1464–1476.
7. Danne T, Nimri R, Battelino B, et al. International consensus on use of continuous glucose monitoring. *Diabetes Care*. 2017;40(12):1631–1640.
8. Fonseca VA, Grunberger G, Anhalt H, et al. Continuous glucose monitoring: a consensus conference of the American Association of Clinical Endocrinologists and American College of Endocrinology. *Endocr Pract*. 2016;22(8):1008–1021.
9. Diabetes Forecast. Continuous glucose monitors and their features. <http://main.diabetes.org/dforg/pdfs/2018/2018-cg-continuous-glucose-monitors.pdf>. Accessed March 20, 2018.
10. Edge J, Acerini C, Campbell F, et al. An alternative sensor-based method for glucose monitoring in children and young people with diabetes. *Arch Dis Child*. 2017;102(6):1–7.
11. Bolinder J, Antuna R, Geelhoed-Duijvestijn P, et al. Novel glucose sensing technology and hypoglycaemia in type 1 diabetes: a multicenter, non-masked, randomized controlled trial. *Lancet*. 2016;2254–2263.
12. Haak T, Hanaire H, Ajjan R, et al. Flash glucose-sensing technology as a replacement for blood glucose monitoring for the management of insulin-treated type 2 diabetes: a multicenter, open-label randomized controlled trial. *Diabetes Ther*. 2017;8(1):55–73.
13. Benkhadra K, Alahdab F, Tamhane S, et al. Continuous subcutaneous insulin infusion versus multiple daily injections in individuals with type 1 diabetes: a systematic review and meta-analysis. *Endocrine*. 2017;55(1):77–84.
14. Diabetes Forecast. Insulin pumps and their features. <http://main.diabetes.org/dforg/pdfs/2018/2018-cg-insulin-pumps.pdf>. Accessed March 20, 2018.
15. Messer LH, Forlenza GP, Sherr JL, et al. Optimizing hybrid closed-loop therapy in adolescents and emerging adults using the MiniMed 670G system. *Diabetes Care*. 2018;41(4):789–796.
16. Bergenstal RM, Garg S, Weinzimer SA, et al. Safety of a hybrid closed-loop insulin delivery system in patients with type 1 diabetes. *JAMA*. 2016;388(13):2254–2263.
17. Garg SK, Weinzimer SA, Tamborlane WV, et al. Glucose outcomes with the in-home use of a hybrid closed-loop insulin delivery system in adolescents and adults with type 1 diabetes. *Diabetes Technol Ther*. 2017;19(3):155–163.

18. El-Khatib FH, Russell SJ, Magyar KL, et al. Autonomous and continuous adaptation of a bihormonal bionic pancreas in adults and adolescents with type 1 diabetes. *J Clin Endocrinol Metab.* 2014;99(5):1701–1711.
19. Russell SJ, El-Khatib F, Sinha M, et al. Outpatient glycemic control with a bionic pancreas in type 1 diabetes. *N Engl J Med.* 2014;371(4):313–325.
20. Russell SJ, Hillard MA, Balliro C, et al. Day and night glycaemic control with a bionic pancreas versus conventional insulin pump therapy in preadolescent children with type 1 diabetes: a randomised crossover trial. *Lancet Diabetes Endocrinol.* 2016;4(3):233–243.
21. Haidar A, Legault L, Messier V, et al. Comparison of dual-hormone artificial pancreas, single-hormone artificial pancreas, and conventional insulin pump therapy for glycaemic control in patients with type 1 diabetes: an open-label randomised controlled crossover trial. *Lancet Diabetes Endocrinol.* 2015;3(1):17–26.
22. Haidar A, Legault L, Matteau-Pelletier L, et al. Outpatient overnight glucose control with dual-hormone artificial pancreas, single-hormone artificial pancreas, or conventional insulin pump therapy in children and adolescents with type 1 diabetes: an open-label, randomised controlled trial. *Lancet Diabetes Endocrinol.* 2015;3(8):595–604.
23. Haidar A, Rabasa-Lhoret R, Legault L, et al. Single- and dual-hormone artificial pancreas for overnight glucose control in type 1 diabetes. *J Clin Endocrinol Metab.* 2016;101(1):214–223.
24. Sherr JL, Tauschmann M, Battelino T, et al. ISPAD Clinical Practice Consensus Guidelines 2018: Diabetes Technologies. *Pediatr Diabetes.* 2018;19(suppl 27):302–325.