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Technology to Optimize Pediatric Diabetes Management and Outcomes

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Abstract

Technology for diabetes management is rapidly developing and changing. With each new development, there are numerous factors to consider, including medical benefits, impact on quality of life, ease of use, and barriers to use. It is also important to consider the interaction between developmental stage and technology. This review considers a number of newer diabetes-related technologies and explores issues related to their use in the pediatric diabetes population (including young adults), with a focus on psychosocial factors. Areas include trend technology in blood glucose monitoring, continuous glucose monitoring, sensor-augmented insulin pumps and low glucose suspend functions, internet applications including videoconferencing, mobile applications (apps), including text messaging, and online gaming.

Keywords

Pediatric diabetes; technology; psychosocial; continuous glucose monitoring; insulin pump; management; outcomes

Introduction

Diabetes remains an incurable yet manageable disease. Type 1 diabetes (T1D), in particular, requires remarkable attention to detail, with the timely administration of insulin multiple times each day; careful attention to dietary intake particularly with respect to the timing,

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quantity, and quality of carbohydrates as well as an understanding of the impact of protein and fat on glycemic excursions; exercise which becomes as much therapeutic as recreational in nature; and frequent blood glucose monitoring (BGM) that provides the basis for all treatment tasks. Type 2 diabetes (T2D) also demands attention to management details although it can often be treated with lifestyle efforts directed at diet and exercise alone, sometimes in combination with oral medications and/or insulin. In addition to these detailed diabetes management tasks, blood glucose (BG) levels are often susceptible to unpredictable changes in association with illnesses and stress, which both create a need for even more frequent BGM.

The management of both T1D and T2D places substantial demands upon both patients and family members. There are opportunities for mitigation of these burdens and associated psychosocial distress with the use of new technologies. The current era has witnessed a remarkable explosion of innovative diabetes technologies that can ease the burden of insulin delivery, simplify BGM and interpretation, and provide guidance to both diet and exercise in the management of lifestyle issues using mobile apps, to name just a few advances.

The current review highlights a number of advanced diabetes technologies that offer benefits to patients with respect to optimizing glycemic control and avoiding severe hypoglycemia. It also describes modern technologies that ease the burdens of glucose monitoring with the use of either traditional handheld meters used for BGM or continuous glucose monitoring (CGM) tools. Use of mobile apps as well as Internet-enabled communication tools is also discussed. We will focus mainly on technological diabetes advances for pediatric and young adult patients with T1D although examples of advances that have been evaluated in the population with T2D are included when needed for completeness. This review covers the following six main areas: recent advances in BGM using trend technology; an update of CGM; insulin pump advancements including sensor-augmented pumps and low glucose suspend functions; Internet applications including virtual diabetes visits and support; mobile apps including text messaging reminders to improve treatment adherence and other tools to support lifestyle efforts; and opportunities with gaming to encourage adherence and provide social support for youth with diabetes.

Trend Technology in Blood Glucose Monitoring

Blood glucose monitoring (BGM) is a vital component of diabetes care. The importance of BGM was established in the landmark Diabetes Control and Complications Trial (1). Increased frequency of daily BGM is associated with lower hemoglobin A1c levels (A1c) (2–4). Self-monitoring of BG provides information to the patient and allows them to determine whether treatment is needed. BG values over time help diabetes treatment teams make decisions about insulin dosing and recommendations for diabetes self-care. Despite the recognized value of BGM, there are several barriers, including pain, cost, insurance coverage, and burden of frequent BGM. In addition, patients can feel frustrated and self-critical if they have BG values that are not in target and these feelings can lead to avoidance of BGM. Strides to improve the experience of BGM have been made in an effort to alleviate some of its burden (5). In the past decade, there have been significant advancements in the realm of BGM. BG meters can store information which can be downloaded by patients and healthcare providers. In addition, downloaded results can be displayed graphically, to identify trends in BG values that may require intervention.

Some BG meters can also provide graphs which display values over time. This information can be used by patients to understand trends in their BG values, as shown in a recent randomized clinical trial (RCT) by Polonsky (2011) and colleagues (6). In this study, insulin-dependent adults with T2D were randomized to two groups. One group received

enhanced usual care, which consisted of quarterly clinic visits focused on diabetes management, free test strips and meters, and A1c. The intervention group consisted of enhanced usual care plus instruction and support for a structured BGM protocol. In this protocol, participants received training using a blood glucose meter that identifies trends. Participants were also given instructions by diabetes educators about how to best identify problematic patterns, and how to treat these issues through lifestyle modification. Results from this study reveal that participants in the treatment group had significant improvement in A1c values over those in the enhanced usual care group, indicating that BG trend technology may hold the potential to improve glycemic control.

Improvements in accessibility of BG information have also been achieved. Blood glucose meters have become smaller and more portable. Recently, a meter was developed that can be used with an iPhone™. The meter can be connected to the phone for a graphical display of BG information. Clinical trial results demonstrate this meter has comparable clinical accuracy to other meters (7). Additional clinical trials are scheduled to take place in the US to evaluate the effectiveness of this new technology. In the adolescent and young adult population, this type of technology may hold particular appeal given the widespread use of smartphones in these age groups.

Advances have also been made in providing real time access to BG information to healthcare providers. Patients now have the capability to upload data from their blood glucose meter to a web-based application which providers can access. Recently, a device used in the military medical setting significantly streamlined the process of transmitting real time BG information to healthcare providers (8). By plugging a device into the meter, BG values were instantly transmitted to healthcare providers and providers were notified of the transmission by email. The provider then reviewed the data and had the ability to send a message back to the family through email. This device has yet to be evaluated in an RCT for impact on glycemic control and quality of life (QOL), however, one can imagine that streamlining communication between families and their treatment teams may help improve diabetes care, reduce barriers for patients and their families, and perhaps reduce diabetes burnout.

Self-monitoring of BG values is an essential piece of diabetes care. However, the frequency of this task can feel burdensome to patients and contribute to diabetes burnout. Technological advances in BGM hold the potential to increase adherence to BGM while improving QOL. Advances in technology may reduce the burden associated with this aspect of self-care and provide more communication between patients and their healthcare providers.

Continuous Glucose Monitoring (CGM)

Real time CGM provides nearly continuous glucose data, offering patients abundant information about current glucose and daily glucose trends. CGM devices are made up of three parts: 1) a disposable glucose sensor which is placed subcutaneously in the interstitial space and changed every 3 to 7 days, 2) a wireless transmitter, connected to the sensor, which sends the interstitial glucose readings to a nearby receiver, and 3) a receiver that displays the glucose readings both numerically and graphically, while refreshing the result every 5 minutes. The system can also provide either auditory or vibratory warning alarms when the glucose value exceeds low or high thresholds (set by the patient) or is rapidly rising or falling. Currently, CGM users must continue to check their finger stick BG levels to calibrate the CGM devices and whenever patient-initiated adjustments to diabetes therapies are needed, as the CGM devices are not approved by regulatory agencies as replacement for BGM. Thus, adoption of CGM requires substantially more time and effort

from the patient and often triggers feelings of frustration and physical discomfort. CGM is also used within closed-loop systems to create an external artificial pancreas. These systems utilize a CGM device to measure interstitial glucose, an insulin pump/pumps to deliver insulin or insulin and glucagon, and a computer-based algorithm for insulin delivery based on glucose levels.

Studies have found that use of CGM improves glycemic control in patients with T1D when worn consistently (9–14). However, youth with T1D show less sustained use of CGM than adults (10). Two recent studies in very young children found similar results. Mauras et al. investigated CGM use in youth with T1D ages 4–9 and found that sensor wear decreased significantly during the 26 weeks of the study and during the last month of the study, less than half of participants (41%) averaged ≥ 6 days/week of CGM use (15). In a study of younger children (<4 years), sensor use also declined during the course of use (16). During the first month of the study, median use was 6.5 days/week. During the last 4 weeks of the study (at 6 months), CGM use declined to a median of 4.7 days/week, with 45% of participants using CGM ≥ 6 days/week. These studies show that sustained CGM use is consistently difficult in youth with diabetes of all ages. Identifying barriers to consistent CGM use in youth is an area of current research.

There are a number of barriers that may prohibit youth from wearing CGM. While CGM provides unparalleled data, it also compounds the burden associated with the usual burden of daily diabetes management. The JDRF CGM trial studied QOL, fear of hypoglycemia, CGM satisfaction, and barriers to CGM use. All participants reported substantial satisfaction with CGM, which was significantly correlated with CGM use (17). Another publication from the same group reported perceived barriers and benefits of CGM use as endorsed by youth, their parents, and adults in the trial (18). Common benefits reported were: availability of glucose trend data, opportunities to correct out-of-range glucose levels, the ability to detect nocturnal hypoglycemia, and the ability to understand the impact of various foods on glucose levels. Frequently reported barriers included: pain associated with sensor insertion, system alarms often considered as ‘nuisance alarms’, and frustration with body issues related to where to place the sensor on the body, skin reactions from the sensor adhesive, and how to carry the receiver on the body. Of note, adults with T1D and parents of youth with T1D were more likely to report benefits while youth were more likely to report barriers of CGM use.

A recent publication examined psychosocial correlates of CGM use in an ancillary study of the JDRF CGM trial (19). Psychological characteristics of youth with T1D, their parents, and young adults with T1D were compared between those using CGM and those in the usual care group (BGM) after six months. Youth, their parents, and young adults appeared to have different psychological responses to CGM use. Two examined variables were state and trait anxiety. State anxiety measures the level of anxiety surrounding a specific event or at a certain time. Trait anxiety measures a more stable personality trait, which manifests as individual differences in the perception of anxiety {Spielberger, 1983 1420/id}. Youth in the CGM group reported more trait anxiety than youth in the BGM group while young adults in the CGM group reported less state and trait anxiety than young adults in the BGM group. Parent-proxy report of youth depression was higher in the CGM group than in the BGM group. Both youth in the CGM group and their parents reported more negative affect around BGM than youth and their parents in the BGM group. On the other hand, adults in the CGM group endorsed less diabetes-related burden than adults in the BGM group. Overall, this preliminary study suggests that CGM use in young adults tends to have a positive psychosocial impact while CGM use in youth tends to have a negative psychosocial impact. These findings suggest a need for additional research aimed at reducing any negative psychological consequences of CGM use, especially in youth.

Similar themes emerge in the studies of younger children noted above. Mauras et al. found, at the end of the 26 week study, there were no differences in fear of hypoglycemia or parental burden related to having a child with T1D between those wearing a CGM and those not wearing a CGM (15). Parents whose children used CGM reported a high degree of satisfaction with the device and the majority of parents (>90%) reported that the CGM made them feel safer than not using the CGM. Tsalikian et al. (16) found parental report of high CGM satisfaction and they attributed the CGM with helping them learn more about fluctuation of glucose levels, treat hypoglycemia and dose insulin, and help them feel safer with regard to hypoglycemia in their young children.

Barriers to CGM use likely contribute to the negative psychological responses noted above. Nonetheless, CGM trials have demonstrated safety and efficacy with respect to improved glycemic control without increased hypoglycemia, particularly for adults with T1D. Pediatric behavioral intervention studies are ongoing to encourage and sustain CGM use in youth with T1D.

Closed-loop insulin delivery systems are in development and testing phases, many during overnight hours with pediatric patients (21–25). One recent study examined the efficacy of using a closed-loop system, overnight, in a camp setting (26). This study aimed to address the issue of real life use of these systems and was completed in three different countries (Israel, Slovenia, and Germany), for 3 days each. This crossover study design had patients use the closed-loop system on one night and a sensor-augmented pump the other night. It was found that use of the closed loop system resulted in significantly fewer episodes of nighttime hypoglycemia and no adverse events were reported. Parental and adult perception of closed-loop systems have been evaluated (27;28). The majority of parents of youth with T1D report trusting and feeling positive about these systems (27). Adults with T1D also reported trust in a closed-loop system and believed it would be helpful and easy to use (28). Future research is needed to examine additional psychosocial factors related to closed-loop systems and to identify the barriers and psychological benefits of this technology, particularly in the pediatric population.

Currently, use of CGM and closed-loop systems have both cost and benefit to patients. It is important to consider many factors when determining if these devices are appropriate for an individual, including patient's current frequency of BGM, willingness to learn and use a new technology, and motivation for wanting to use the new technology.

Ambulatory Glucose Profile

Hemoglobin A1c is the laboratory result that is used to understand how well a patient is managing their diabetes, with guidelines for optimal control. The use of A1c in this manner has been questioned because, as an average, it does not account for glycemic variability. Given this issue, and the concern that CGM data is often difficult to interpret, an expert panel of diabetes specialists recently convened to create a standardized display of CGM data (29). The result was an initial view of the ambulatory glucose profile; a virtual dashboard that displays statistics for use in clinical and research settings. These statistics reflect glucose variability, percent of time spent in and out of target range, and area under the curve and coefficient variation. The second part of the dashboard is a visual display comprised of two components, the standard day and the daily view. The standard day is the average of multiple days which are collapsed and plotted according to time. The daily view looks at each individual day included in the standard day display, which allows for identification for patterns on specific days of the week. Standardization of glucose profiles aims to make diabetes-related data more user friendly for patients and providers, which may lead to improved diabetes management.

Advances in Insulin Pump Therapy

Insulin pump therapy is increasingly used for insulin delivery in pediatric and young adult patients with T1D. In the T1D Exchange, 50% of patients ages 1–93 years old received insulin pump therapy; the proportion of children, teens, and young adults <26 years old treated with an insulin pump ranged from 31% in those <6 years old to 51% in those 18–25 (30). However, only 6% of patients in the T1D Exchange used CGM, with lower rates (2–3%) in the pediatric and young adult patients (31). Recent publications speak to the combined use of sensor-augmented insulin pump therapy.

In the STAR3 Study of **S**ensor-Augmented Pump **T**herapy for **A**1C **R**eduction, 485 patients with T1D, including 156 youth, were randomized to 1-year of sensor-augmented pump therapy or multiple daily injections (MDI). All patients had suboptimal control at entry with A1c values 7.4–9.5% and were either insulin pump-treatment naïve or had not used a pump for the past 3 years. In this multi-center RCT, baseline mean A1c of 8.3% in both groups decreased to 7.5% in the sensor-augmented pump group and to 8.1% in the MDI group, a significant difference of 0.8% (P<0.001). Risk of severe hypoglycemia and weight gain were similar between treatment groups. In the pediatric participants, patients in the sensor-augmented pump group were more likely to attain ADA age-specific target A1c values than the injection-treated patients. Notably, children compared to adolescents were more likely to wear the CGM sensors (p=0.025) (32).

QOL and treatment satisfaction were also assessed in the STAR3 study. Health-related QOL did not differ between treatment groups in adult participants, youth, or caregivers of the children (33). Notably, diabetes-specific QOL related to fear of hypoglycemia worry and behavior scales was more favorable for adults in the sensor-augmented pump group. Only the behavior subscale was significantly improved among caregivers in the sensor-augmented pump group versus the injection group. For adults, children, and the caregivers, between group differences in change in measures of treatment satisfaction related to convenience, efficacy, and preference all favored the sensor-augmented pump group (P<0.001) (33). Increased treatment convenience was related to improved treatment satisfaction (34). There was greater treatment satisfaction when adults reported reduced social burden, when the caregivers reported reduced interference of the treatment, and when both the adults with T1D and the caregivers of the youth reported increased efficacy of treatment. For children, satisfaction with treatment was only related to convenience. Thus, while sensor-augmented pump therapy offers opportunities to improve glycemic control without increasing the risk of severe hypoglycemia, opportunities to reduce burden and improve psychosocial outcomes vary by age.

A few studies have assessed sensor-augmented pump therapy at onset of T1D in youth. The ONSET Study randomized 160 European youth, ages 1–16 years old, to either sensor-augmented pump therapy or standard pump therapy within 4 weeks of the diagnosis of T1D (35). Glycemic control assessed as A1c was the same between groups at all time points. However, there was no severe hypoglycemia in the sensor group while there were 4 episodes in the pump only group (P=0.046). Notably, more frequent sensor use was associated with greater preservation of C-peptide after 52 weeks, with a significant difference found in fasting C-peptide levels for teens, ages 12–16 years old in the sensor-augmented pump group versus the pump only group. Throughout the study, QOL did not differ between treatment groups. Again, infrequent sensor use among pediatric patients remained a deterrent to its routine use.

The Metabolic Control Study in the USA randomized 68 patients (ages 6–45) with T1D within 7 days of diagnosis to either 3 days of hybrid closed-loop followed by sensor-

augmented pump therapy for 1 year or usual care (36). Most patients were youth as the mean ages of the 2 groups were 12.7 and 14.7 years, respectively. The primary outcome was preservation of C-peptide levels after 12 months. The 1-year outcome data presented at the ATTD (Advanced Technologies and Therapeutics for Diabetes, Paris 2013) revealed no difference in C-peptide between treatment arms (37).

The next advancement in sensor-augmented pump therapy stems from low-glucose suspend (LGS) functionality in which there is an automatic suspension of the pump's basal insulin delivery following the detection of sustained hypoglycemia by the sensor. There are a few recent publications describing this advancement and another large multi-center trial underway in the USA. A short-term 3-week study in the UK evaluated the LGS function in which the basal rate was shut off for up to 2 hours following trigger by the CGM glucose threshold that was individually set (38). In 31 adult patients, the LGS was associated with reduced nocturnal hypoglycemia in those patients who had the highest rate of nocturnal hypoglycemia during the 2 week baseline run-in period that preceded the three week study. After the LGS of basal insulin delivery, the median sensor glucose level was 70 mg/dL and rose to 148 two hours later. Use of the LGS function was associated with a reduction in anxiety and greater nighttime security reported by the patients.

The next study reports use of the LGS function with sensor augmented pump therapy in 21 youth with T1D, ages 1–18 years old, with a similar 2-week baseline period followed by 6 weeks of LGS (39). Mean occurrence of hypoglycemic excursions <70 mg/dL was significantly reduced from 1.27 to 0.95 times daily (P=0.01) without any increase in mean CGM glucose levels comparing the LGS-off time to the LGS-on time. Overall, there was no severe hypoglycemia or DKA, suggesting that LGS may provide opportunities to improve management and psychosocial outcomes across the age span.

In addition to these two outpatient studies of LGS, there was a recently published in-clinic study with and without the LGS functionality following standard exercise in a cross-over study of 50 patients with T1D ages 17–58 (40). Patients were followed for 4 hours following the exercise in this in-clinic ASPIRE Study (**A**utomation to **S**imulate **P**ancreatic **I**nsulin **Re**sponse). With LGS, the duration of hypoglycemia <70 mg/dL was significantly less (139 versus 171 minutes, P=0.006). In addition, the mean glucose at the end of the 4 hours was higher with the LGS (91 versus 66, P<0.001) and no glucose values exceeded 250 mg/dL.

The LGS pump feature is not yet available in the USA although it has been available in Europe since 2009. We await the results of a multi-center RCT comparing LGS pump therapy with standard pump therapy in patients at high risk for nocturnal hypoglycemia. The ASPIRE In-Home Study should provide such results later this year.

Video Conferencing Technology

The use of video conferencing technology has become increasingly popular in the field of healthcare. This technology has been used to provide interaction among patients and providers between visits and has been used for mental health and health behavior interventions in adults and youth. An RCT comparing a web-based psychotherapy treatment for depression to clinic-based psychotherapy treatment in people with T2D found that the intervention was effective in reducing depressive symptoms and reducing diabetes-specific emotional distress (41). These results demonstrate that mental health treatment using video conferencing may be a viable treatment option for adults with diabetes.

The management of children and adolescents living with chronic conditions is multifaceted and complex. Video conferencing technology is being used as a way to provide more contact between healthcare providers and children and their families living with chronic conditions

(42). Recently, Harris and colleagues delivered a behavioral family systems therapy (BFST) intervention to pediatric patients with T1D and their families and compared two groups; those receiving the intervention through video conferencing, and those receiving the intervention in the diabetes clinic (43). Preliminary results reveal that families in the video conferencing group reported a high level of satisfaction with the intervention. These families also completed more intervention sessions than families who participated in clinic although this difference was not statistically significant. These results indicate that families who have a child with T1D may be open to and feel satisfied with receiving psychological services from their providers in an online environment.

Caring for children with T1D requires effort and coordination from healthcare providers both in and outside of the diabetes clinic. School staff, particularly school nurses, is an integral part of the treatment team. Video conferencing provides an opportunity for clinic providers to communicate with school nurses for care coordination. A study conducted by Izquierdo and colleagues (44) compared a video conferencing intervention to usual care, which consisted of medical visits every three months and phone contact between clinic providers and school nurses as needed. The intervention consisted of monthly virtual meetings with the patient, school nurse, and T1D providers in addition to usual care. Over the six month study period there was a significant difference in A1c between the two groups, with the intervention group showing a reduction in A1c and the usual care group showing an increase in A1c. The intervention group also had significant improvement in several subscales of the Pediatric Diabetes QOL questionnaire. Finally, the intervention group had significantly fewer urgent diabetes-related phone calls initiated by the school nurse as well as fewer hospitalizations and emergency department visits.

The use of video conferencing has demonstrated potential in two areas of diabetes care, providing psychotherapy to patients and their families and facilitating communication between treatment team members. However, ethical and professional issues need to be considered when attempting to deliver services using this technology. Security and privacy need to be ensured in an online environment and professional organizations are starting to address these issues (http://www.apa.org/about/governance/good-governance/council-backgrounder.pdf). In addition, guidelines may help systematically describe these interventions in the research literature, improving the ability to evaluate the effectiveness of these programs (45;46).

Smartphone Technology

Text messaging is the primary mode of communication among adolescents and young adults. Recent survey data finds that ≥ 25% of teenagers, ages 12–17 own a smartphone, and the majority (77%) owns a cell phone (http://pewinternet.org/Reports/2012/Teens-and-smartphones.aspx; retrieved 10/31/12). There is enormous opportunity in health education, prevention, and intervention research to assess the feasibility and benefits of mobile health programs among adolescents and young adults.

Text messaging for improved diabetes management has been evaluated in the pediatric population and has been shown to be acceptable to patients (47) and to improve diabetes self-efficacy and treatment adherence (48). A meta-analysis of mobile phone interventions in patients with diabetes found a reduction in A1c of 0.3% for those studies including only patients with T1D (49). More recently, Markowitz et al. (50), conducted a study examining the feasibility and acceptability of a daily text messaging intervention, focused on nutrition and healthy lifestyle activities, in youth with diabetes. Participants were randomized to receive a pamphlet about healthy eating and exercise, or to receive daily text messages regarding healthy eating and exercise, many with links to a website, Bodimojo.com, for

more in-depth information. The majority of participants (82%) indicated that the text messaging intervention helped them follow through with their health goals and offered positive feedback.

In addition to text messaging, the use of smartphone applications in diabetes management has been evaluated. Charpentier et al. (2011) (51) and colleagues investigated the use of a smartphone app in adults with T1D. The app contained an advanced bolus calculator that takes multiple patient factors into account, algorithms for adjustment of carbohydrate ratio and insulin dosing, and the capability to transmit data to the medical team. Study participants were assigned to one of 3 groups: 1) usual care, including the use of a paper logbook, 2) usual care plus use of the software and 3) use of the software with phone consultations every 2 weeks and in-person visits at the study endpoint. Results reveal a statistically significant difference between the usual care group and the group using the software and biweekly phone visits, with the software group having a lower A1c at 6-month follow-up.

A few review papers have examined the numerous mobile applications available and made recommendations for patients. Recently, Garcia et al. systematically examined all smartphone applications and rated them on a number of different factors (52). They concluded that, for the iPhone™, the most usable app was Diabetes Diary and the least usable was GluCoMo. For the Android, the most usable app was Glucool Diabetes and the least usable was Track3 Diabetes Planner. A review focused solely on Android applications (53) rated apps on a number of different factors and found that the highest rated apps were Glucool Diabetes, OnTrack Diabetes, Dbees, and Track3 Diabetes Planner. In addition, some newer apps (MyGlu, Bant), have the capability to connect patients with one another in realtime; thus, providing opportunities for additional peer support around diabetes management.

Research has found that use of mhealth technology with pediatric patients is acceptable and often user-friendly. Barriers to use include not having access to a smartphone and the potential for habituation to daily messages and/or daily use of an app. mHealth interventions may also have the ability to improve psychosocial functioning by using social media to connect youth with diabetes to one another for peer support as well as allow for diabetes management tasks to feel more routine by integrating these activities with other daily activities captured by smartphones.

Games to Enhance Adherence and Improve Outcomes for Youth with T1D

The unending nature of diabetes management can be exhausting and isolating, particularly for youth with T1D and their families. The current era offers opportunities to encourage engagement of youth in their care by using the Internet or other interactive technologies such as digital games. Such platforms allow for teachable moments and offer possible interactions with others to avoid isolation through participation in social networks. Such approaches offer burgeoning opportunities for the future. However, there are a few examples that warrant presentation.

A number of years ago, our group piloted one of the first handheld devices that encouraged BGM for youth with T1D by offering a motivational game in which youth would guess their 4th blood glucose check of the day following 3 earlier BG checks in the DAILY Trial (**D**aily **A**utomated **I**ntensive **L**og for **Y**outh) (54). The glucose values were graphed on a handheld device (PDA) along with other displays of carbohydrate intake and previously administered insulin doses. The handheld device wirelessly communicated with a BG meter with diabetes management software and had a wireless modem for transfer of the data to a secure server.

In a 4-week pilot study, 40 youth, ages 8–18, each received the PDA with half randomized to also participate in the motivational game. The game group transmitted significantly more BG data than the control group (P<0.001) and also had less hypoglycemia (P<0.001). Notably, the game group also had a significant increase in diabetes knowledge compared with controls (P<0.005). Even this simple motivational game appeared to increase BGM frequency, reduce hyperglycemia, and improve diabetes knowledge. Thus, more sophisticated games may offer opportunities to improve glycemic control in youth.

Another game, called DIDGET®, incorporates a version of a commercial BG meter that connects with the Nintendo® game system (55). The meter contains an algorithm that accounts for the frequency, timing, and results of BGM in order to determine reward points which allow access to different levels of the game. In a multi-center study, accuracy of the meter was confirmed during an in-clinic assessment involving 147 youth and young adults with T1D, ages 5 to 24 years old. A follow-up 3–5 day in-home study assessed usability and satisfaction with the device in 58 of the patients. The meter's accuracy and precision were confirmed. Satisfaction with the system was good to excellent as assessed by the patients, their parents or guardians, and health care professionals. Most reported that the system was easy to use, motivating, and encouraged BGM. Most health care professionals also believed that this motivational monitoring system fulfilled a need in diabetes management.

There is a new diabetes educational and support game under development in Israel, called Makomba™, which utilizes a web-based format (56). The game offers opportunities for education and engagement of youth with T1D. Youth create their own avatars and can play the game either alone or with others remotely. The game includes activities related to various aspects of T1D management to encourage implicit learning. In a brief pilot study in Israel, youth randomized to receive the game along with a computer with Internet access versus youth who received a computer with Internet alone demonstrated improved QOL. Longer term, international studies are needed to confirm the efficacy. There are ongoing needs to identify approaches to engage youth in diabetes management tasks in order to help optimize their glycemic control and prepare them effectively for future diabetes self-management and transitions in care from pediatric to adult providers.

Conclusion

In this review, we have examined a number of newer technologies for pediatric diabetes management. While there are many potential benefits of using these technologies, there are also barriers to the use of some, and questions about how to mitigate these barriers for optimal diabetes outcomes. Future studies may help to clarify these issues. In addition, as newer technologies are developed, it is important for researchers to identify potential barriers to use, as well as any psychosocial issues related to use, and address these early in the design and implementation of the technology.

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