Psychology, Technology, and Diabetes Management

Linda A. Gonder-Frederick, Jaclyn A. Shepard, Jesse H. Grabman, and Lee M. Ritterband
University of Virginia

Use of technology in diabetes management is rapidly advancing and has the potential to help individuals with diabetes achieve optimal glycemic control. Over the past 40 years, several devices have been developed and refined, including the blood glucose meter, insulin pump, and continuous glucose monitor. When used in tandem, the insulin pump and continuous glucose monitor have prompted the Artificial Pancreas initiative, aimed at developing control systems for fully automating glucose monitoring and insulin delivery. In addition to devices, modern technology, such as the Internet and mobile phone applications, have been used to promote patient education, support, and intervention to address the behavioral and emotional challenges of diabetes management. These state-of-the-art technologies not only have the potential to improve clinical outcomes, but there are possible psychological benefits, such as improved quality of life, as well. However, practical and psychosocial limitations related to advanced technology exist and, in the context of several technology-related theoretical frameworks, can influence patient adoption and continued use. It is essential for future diabetes technology research to address these barriers given that the clinical benefits appear to largely depend on patient engagement and persistence of technology use.

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Technology plays a larger role in day-to-day diabetes management than perhaps in any other chronic illness. In fact, it is impossible for most people with diabetes, especially those with Type 1 diabetes (T1D) or Type 2 diabetes (T2D) requiring insulin, to achieve optimal diabetes control without the use of some form of technology. (See Hunter, 2016, for a review of T1D and T2D.) Some of the most profound technological advances over the past decade have occurred in devices that improve patients’ ability to self-administer insulin and monitor blood glucose (BG) levels. Insulin therapy is different from most medication regimens, which have a fixed dose and timing. The body’s need for insulin changes throughout the day depending on physiological and behavioral factors, including current BG, metabolic demand, food intake, and physical activity. Ideally, insulin therapy duplicates normal glucose metabolism as closely as possible, achieved by following intensive treatment regimens which vary the dose and timing of insulin to “match” physiological needs. BG monitoring is also critical because glucose levels vary throughout the day, and monitoring provides essential information to guide insulin dosing, as well as feedback about the impact of food intake and physical activity on BG.

In the early 1980s, two technologies emerged that radically altered the paradigm of diabetes self-management: (a) reflectance meters which provided immediate and accurate BG readings and (b) continuous subcutaneous insulin infusion (CSII), or insulin pumps, which delivered insulin in a more physiologic, precise pattern. These triggered a movement of rapid technological development that continues today leading to “smart” insulin pumps, capable of sophisticated functions such as calculating insulin doses and delivering insulin in a graded fashion, and to continuous glucose monitoring (CGM) systems, providing glucose readings and direction/rate of change every few minutes.
throughout the day. In combination, smart pumps and CGM devices triggered the global Artificial Pancreas (AP) project, aimed at developing a fully automated glucose control system that incorporates algorithms to calculate current insulin needs and deliver insulin automatically based on glycemic patterns. Thus, this fully automated AP is conceived as a “closed-loop” system that requires minimal human interaction and effort, thereby mimicking the biologic process of glucose metabolism. Presently, laboratories around the world are designing and testing AP systems, although none are yet ready for commercial use. However, AP research has led to other important technological advances, such as the integration of CSII and CGM in open-loop systems which do require human operation and decision-making. One example is the sensor-augmented pump (SAP), currently available for commercial use, as well as SAP with the capacity to suspend insulin when glucose readings are low.

In addition to these devices, there is a growing effort to utilize technology to address patient needs for support, education, and intervention in the face of the significant emotional and behavioral demands of diabetes management. A potential way to address this challenge is through eHealth, a term which encompasses a diverse range of electronic/digital technologies focused on health applications delivered via the Internet, smartphones, and sensors, allowing for feedback and potential data exchange to health care providers. Currently, the development and implementation of eHealth products is advancing far more quickly than the science needed to adequately test them, presenting difficulties to health care providers and patients.

In spite of technological advances, diabetes treatment remains complex and optimal diabetes control continues to be elusive. A major issue is patient acceptance and uptake of technologies, as well as numerous barriers to long-term usage. Many of these barriers are psychological and behavioral factors that influence individual motivation, capability, and decisions regarding technology use. This review will focus on psychobehavioral factors and processes that influence adoption and use of current technologies, beginning with a theoretical framework for understanding a patient-centered approach to diabetes technology.

**Theoretical Framework**

The theoretical models most relevant to adoption and use of diabetes technology include the health belief model (HBM), unified theory of acceptance and use of technology (UTAUT), and diffusion of innovation theory (DIT). (See Gonder-Frederick, Shepard, & Peterson, 2011, for a review.) Both HBM and UTAUT highlight the role of an individual’s perceptions, attitudes, and beliefs in health care decisions including the use of technology (Venkatesh & Davis, 2000). Some of the key beliefs and perceptions are personal vulnerability to health problems, costs and benefits of health behaviors, self-efficacy to succeed, and usefulness and ease of use of technology. Recent AP studies have found the perceived benefits of using the device, such as BG control, outweighed perceived costs/burdens, such as calibration problems (Barnard et al., 2014) and that the constructs of perceived usefulness and ease of use predict likelihood of future adoption of this technology (Bevier et al., 2014).

DIT addresses the dissemination of innovative ideas and products through groups and populations, not individuals, and factors influencing widespread adoption (Rogers, 1995). DIT is described on a bell curve (see Figure 1). Across time, innovations are adopted first by innovators and early adopters, followed by the early majority and late majority, and finally laggards. As Figure 1 shows, after 30+ years the insulin pump has barely progressed beyond dissemination into the “early majority” and CGM is just moving into “early adoption,” while BG meters have essentially permeated the T1D population. DIT recognizes that the process of adoption is guided by population attitudes (e.g., favorable impressions) and experiences (e.g., perceived rewards). Therefore, decisions regarding technology adoption are highly dependent on subjective perceptions, and not solely a function of objective utility or benefits. This means that, even if devices can have clear clinical benefits, they may not gain widespread adoption and use by patients. For this reason it is crucial to consider psychobehavioral factors in any model of diabetes technology development and use. In the next section, relationships between psychobehavioral
factors and technology use will be examined for the major devices designed for BG monitoring and insulin delivery.

Diabetes Management Technologies

BG Meters

The first meter for self-monitoring of BG (SMBG) was produced in 1970 and improvements to SMBG technology in the 1980s culminated in increased home meter use, although evidence for the clinical benefits remained equivocal (see Clarke & Foster, 2012 for a review). The Diabetes Control and Complications Trial (DCCT) definitively demonstrated the clinical benefits of intensive insulin therapy in 1993, which changed the paradigm for diabetes treatment forever (The DCCT Research Group, 1993). Subsequent studies confirmed that more frequent SMBG related to better diabetes control in T1D (Schütt et al., 2006; Miller et al., 2013). Currently, the American Diabetes Association (ADA) recommends six to 10 daily readings for optimal control for patients with T1D (Chiang, Kirkman, Laffel, & Peters, 2014). SMBG technology has continued to improve and become more user friendly, making readings faster, easier and less painful. Recent developments have focused on data management and connectivity and today SMBG readings can be uploaded to computers, smart phones, and gaming consoles. In addition, some meters can now provide insulin dosing advice. Figure 1 shows that SMBG is currently used by nearly all T1D patients and the majority of T2D patients taking insulin in the United States, although use is much lower in developing countries.

Although SMBG is easier than ever, behavioral challenges remain. Large patient data sets, such as the T1D Exchange Registry, indicate 16% of patients check their BG three or fewer times per day (Beck et al., 2012). Barriers to adequate SMBG include low socioeconomic status, ethnic minority status and less education, as well as poor understanding about the purpose and beneficial use of SMBG results (Karter, Ferrara, Darbinian, Ackerson, & Selby, 2000; Wagner, Malchoff, & Abbott, 2005). For some patients, SMBG may be burdensome, intrusive, or anxiety provoking (Mollema, Snoek, Heine, & van der Ploeg, 2001; Polonsky, 2002; Wagner et al., 2005). Despite barriers, the majority of T1D patients check their BG four or more times daily, indicating that patient-perceived benefits generally outweigh costs. In younger children with T1D, SMBG frequency is even higher, likely due to parental control over diabetes management, but frequency drops significantly in adolescence (Beck et al., 2012).

Figure 1.  Estimates of rates of adoption of various diabetes technologies with data retrieved from ¹Beck et al., 2012, ²Martin et al., 2006, ³Miller et al., 2013, and ⁴Wong et al., 2014.
While the positive impact of SMBG in T1D is well-documented, in non-insulin-treated T2D the benefit is debatable. Some studies find no association between frequent SMBG and improved glycated hemoglobin levels (HbA1c; Davis, Bruce, & Davis, 2006) while others find that intensive SMBG can worsen quality of life (QOL) and increase anxiety and depression (Simon et al., 2008). However, recent research suggests that structured SMBG programs with systematic guidance and feedback can improve control and well-being in these patients (Fisher et al., 2012; Polesky et al., 2011).

**CSII**

CSII, or insulin pump therapy, was introduced nearly 40 years ago to improve glycemic control by more effectively imitating biological insulin secretion (for a review, see Pickup, 2012). Its more traditional counterpart for intensive therapy, multiple daily injections (MDI), or basal-bolus therapy, requires manual injection of long-acting insulin (basal) along with boluses of fast-acting insulin before or between meals. Use of insulin “pens,” have increased patient acceptance of MDI due to convenience and less painful injections (Pickup, 2012). In contrast, the pump is a portable device worn on the body that infuses fast-acting insulin via a subcutaneous cannula, delivering a slow continuous basal rate as well as premeal and correction boluses. Current “smart pumps” allow patients to program multiple changes in daily basal dose, and deliver boluses in complex patterns to better match changing insulin needs, with features to promote ease of use, including bolus calculators, alarms, touch screens, carbohydrate databases, and infrared and Bluetooth technology (Schaeffer, 2013; Zisser et al., 2008). Although on the market for decades, only a slight majority of T1 adult patients use CSII—an estimated 56% of those with T1D in the United States (Beck et al., 2012). Rates of pump use in T1 U.S. youth are comparable, with an estimated 22–46% using CSII (Beck et al., 2012; Paris et al., 2009). However, these adult and upper-end youth rates are likely overestimates because they come from the T1D Diabetes Exchange Registry, comprised of individuals who attend specialist clinics.

Improvements in glycemic control are found in both adult and pediatric T1D patients with CSII, especially those in poor control (Boland, Grey, Oesterle, Fredrickson, & Tamborlane, 1999; DCCT Research Group, 1994; Pickup & Sutton, 2008). Reduction of hypoglycemia, especially severe episodes, can be another advantage to CSII. A meta-analysis comparing MDI and CSII concluded that hypoglycemia was reduced in adult and pediatric patients with CSII, and for patients with recurrent severe hypoglycemia, episodes decreased by 75% (Pickup & Sutton, 2008). Pediatric studies have also shown a significant reduction in diabetic ketoacidosis, though this can continue to be a risk for some youth using CSII (Hirose, Beverley, & Weinger, 2012; Steindel, Roe, Costin, Carlson, & Kaufman, 1995). In addition, research shows improvements in QOL, with extensive evidence indicating that CSII provides adults and youth with increased lifestyle flexibility, especially related to diet, sleep, and leisure activities (Chantelau, Schifters, Schütze, & Hansen, 1997; Hirose, Beverley, & Weinger, 2012). However, these conclusions are limited by methodological issues in many studies, including cross-sectional or short-term designs and small, often biased subject samples.

Despite well-documented advantages, not every patient experiences improved control and many patients discontinue CSII. Discontinuation rates differ across studies, with estimates ranging from 0% to 32% (de Vries, Grushka, Lebenthal, Shalitin, & Phillips, 2010; Weissberg-Benchell, Antisdell-Lomaglio, & Seshadri, 2003). Behaviorally, CSII is demanding, requiring more consistent engagement and management from the patient and family (Gonder-Frederick et al., 2011). For parents, worries about pump performance and overinsulinization can be barriers (Hirose et al., 2012). Pubertal status is also associated with higher rates of discontinuation (de Vries et al., 2010). Body image concerns are particularly salient for adolescents and a main reason females are deemed high risk for discontinuation (Ritholz et al., 2007). A multiyear follow-up of 101 youth who used CSII found a discontinuation rate of 18%, with diabetic ketoacidosis, burnout, and infusion site problems as the main reasons cited (Wood et al., 2006). Those who discontinued had significantly higher HbA1c levels, and also a significantly lower SMBG frequency. Depression may also play a role in discontinuation. In another long-term follow up, CSII discontinuation was significantly higher in adoles-
cents whose depression increased (Wong, Dolan, Yang, & Hood, 2014). HbA1c was higher in depressed adolescents in both the pump and MDI groups. These findings underscore the importance of patient screening for depression as part of the selection process and treatment planning.

Based on barriers to pump use, and to maximize clinical benefits, there is an acknowledged need for patient selection guidelines. In practice, patient selection appears to be biased toward certain socioeconomic and demographic groups, with more nonminority and privately insured pump users, who have two caretakers in the home and caretakers with college degrees (Wong et al., 2014). The ADA offers general guidelines that are more in line with a human factors perspective, including motivation, willingness to collaborate with diabetes health care professionals, capability to use the technology, adherence to frequent SMBG (a proxy variable for diabetes behavioral engagement), and ability to translate BG information for pump use (ADA, 2004). The American Association of Diabetes Educators (AADE) also underscores the importance of psychosocial factors such as effective coping strategies, adequate social support, and the ability to problem solve in diabetes management (AADE, 2014). Unfortunately, there is no consensus or recommendation regarding how to measure these factors objectively. Adequate patient education and training on CSII use is also recommended; however, there are no standardized requirements to measure patient competence (AADE, 2014).

CGM

CGM, developed over the past decade, measures glucose levels in real time every few minutes, allowing patients to detect and respond to BG extremes promptly and to increase awareness about the effects of insulin, food, physical activity, and other factors. CGM uses a disposable sensor inserted under the skin, which reads glucose levels in interstitial fluid every 5 min. Glucose information is transmitted wirelessly from the sensor to a receiver, which allows the patient to view current glucose levels as well as direction and rate of change. CGM also incorporates high and low alarms (Chase & Messer, 2010). CGM is not currently Food and Drug Administration (FDA) approved for clinical decision-making due to challenges with accuracy, especially in the hypoglycemic range, resulting in a need for patients to continue performing daily finger sticks to confirm CGM readings. Rates of CGM use have steadily increased over the past decade, with estimates that 5% of youth and 18% of adults with T1D currently use it (see Figure 1; Wong et al., 2014). CGM use in T2D is controversial and understudied; however, some findings suggest it can serve as a useful educational and motivational tool for these patients (Allen, Fain, Braun, & Chipkin, 2008).

There are well-documented clinical benefits of CGM use including improved glycemic control with no increase in hypoglycemia (Juvenile Diabetes Research Foundation [JDRF] CGM Study Group, 2008). A recent meta-analysis of six randomized controlled trials confirmed that HbA1c levels decrease significantly, with the most improvement in patients in poorer control and those who engaged in more frequent CGM use (Pickup, Freeman, & Sutton, 2011). The JDRF CGM study group found a significant decrease in HbA1c in adults 25 years and older, who engaged in more consistent CGM use (at least 6 days per week) compared to younger age groups (Tamborlane et al., 2008). The improvements in glycemic control for those who use CGM more consistently underscore the importance of patient selection, education and training prior to initiating CGM to promote long-term adoption.

CGM may also have psychosocial benefits, including improved QOL and treatment satisfaction, though results are mixed. In a survey of 877 T1D adults using CGM, the majority reported increased feelings of safety from hypoglycemia during physical activity, sleeping, and driving, as well as improved motivation and self-efficacy in diabetes self-care (Polonsky & Hessler, 2013). Other studies have found that CGM use is associated with less diabetes-related burden, decreased fear of hypoglycemia (FoH), and increased treatment satisfaction in adult and pediatric patients (Cemeroglu et al., 2010; Hommel et al., 2014; Markowitz, Pratt, Aggarwal, Volkening, & Laffel, 2012). Other studies found no negative psychosocial effects with CGM, with no differences between youth using CGM or SMBG in diabetes-specific QOL, parental FoH, or diabetes-related distress (Mauras et al., 2012; JDRF CGM Study Group, 2010).
In spite of these benefits, long-term CGM use is difficult to achieve, particularly for youth and young adults (JDRF CGM Study Group, 2008). Behavioral barriers contributing to the technology’s “hassle factor,” are frequent false alarms, sensor discomfort or failure, and discrepancies between CGM and SMBG (Chase & Messer, 2010; Tansey et al., 2011). The profusion of data generated by CGM creates anxiety for some patients (Ritholz, 2008) and can be difficult to interpret meaningfully (Polonsky & Hessler, 2013), and physician review of the data and adequate patient education may not occur (Gonder-Frederick et al., 2011). In fact, fewer than one third of adults and just over half of caretakers who use CGM download data for review (Wong et al., 2014; Wong, Neinstein, Spindler, & Adi, 2015), highlighting the need for training programs to teach patients how to interpret and utilize CGM feedback. Patient characteristics considered critical for long-term success with CGM include willingness to use CGM consistently, adequate coping skills for CGM-related hassles, and perceived support (Hirsch, 2009; Ritholz et al., 2010). Like CSII, CGM use is associated with socioeconomic factors including higher education and income, and private insurance, as well as clinical variables such as longer diabetes duration and pump use (Wong et al., 2014).

**SAP Therapy**

SAP integrates CGM and smart pump technology, allowing the devices to work in tandem in an open-loop glucose control system that transmits CGM readings wirelessly to a pump (see Cengiz, Sherr, Weinzimer, & Tamborlane, 2011, for a review). Insulin is not automatically delivered as it is in the AP, which requires control algorithms to calculate the body’s metabolic needs. SAP trials have generally yielded positive clinical benefits including improved BG control and reduced hypoglycemia in pediatric and adult patients (Bergenstal et al., 2010; Slover et al., 2012). Achieving benefits with SAP also appears to depend highly on consistent use, so issues of patient acceptance and adherence are fundamental. The multicenter Star-3 study found that using SAP 40–60% of the time lowered HbA1c by .64%, compared to 1.0% or more when used 80% of the time (Bergenstal et al., 2010). Positive clinical results also depend on positive changes in self-management, as demonstrated by a randomized crossover study of patients on and off SAP which showed increased frequency of daily boluses and temporary basal rate changes with SAP (Battelino et al., 2012).

There is growing evidence that SAP use is associated with positive patient-centered outcomes in pediatric and adult T1D, including reduced FoH and increased treatment satisfaction (Bergenstal et al., 2010; Cemeroglu et al., 2010; Nørgaard et al., 2013). In a follow-up study, 66% of participants maintained these improvements and continued SAP (Schmidt & Nørgaard, 2012). As with other diabetes technology, it is important to consider psychological and behavioral preparedness for SAP, including realistic patient expectations regarding the effort required (Cemeroglu et al., 2010).

**AP**

In 2006, the JDRF launched the AP project, led by Dr. Aaron Kowalski, the JDRF vice president of research, to accelerate research to develop closed-loop glucose control to “close the loop” in diabetes treatment by fully automating glucose monitoring and insulin delivery. This ambitious goal was made possible by the development of CGM and “smart” CSII technology (see Cobelli, Renard, & Kovatchev, 2011, for a review). “Bihormonal” systems that also deliver glucagon to raise BG exist but are beyond the scope of this review (see Russell et al., 2012). The JDRF AP Project created a partnership with the diabetes technology industry to prioritize research necessary to produce these automated systems. Because technology is not yet capable of duplicating normal glucose metabolism perfectly, ongoing research and developments are needed to improve devices. In addition, an AP requires the development of a controller system to integrate CGM and insulin pump data via algorithms to predict metabolic needs. In 2009, the National Institute of Diabetes and Digestive and Kidney Diseases expanded the AP Project by forming a consortium with JDRF to prioritize this research and, in 2010, the European Commission formed the AP@Home project, making this a multinational effort (Peyser, Dassau, Breton, & Skyler, 2014).

Numerous studies have compared glucose control achieved with AP systems to CSII alone, with generally positive results in adults (Breton et al., 2012; Hovorka et al., 2011; Kovatchev et al., 2013) and children (Hovorka et al., 2011; Nimri et al., 2013), including those as young as 3–6 years old (Dauber et al., 2013). Glycemic improvements include more time in target BG range, lower mean BG, and less hypoglycemia. However, currently AP development is limited by several factors, including the time lag of CGM readings and insulin absorption in the body (see Cobelli et al., 2011; Thabit & Hovorka, 2014). Recent studies have tested AP systems under more challenging circumstances that better reflect real world conditions, with exercise, “unannounced” meals, and alcohol intake (Dassau et al., 2013; Elleri et al., 2014). Studies are testing AP outpatient use over longer time periods to determine the feasibility of home use, with published trials ranging from several days (Kovatchev et al., 2013; Russell et al., 2014) to 3 weeks (Hovorka et al., 2014) and ongoing trials lasting up to 3 months.

To date, AP research has necessarily focused on developing and testing the performance and safety of systems,
with few studies incorporating patient-centered outcome measures. However, in two recent studies, theoretical constructs from HBM and UTAUT predicted adult patient acceptance of AP, including perceived benefits, usefulness, and ease of use (Bevier et al., 2014; van Bon, Brouwer, von Basum, Hoekstra, & de Vries, 2011). In studies of adolescent and parent reactions to home AP use (Barnard et al., 2014; Hovorka et al., 2014), positive patient-reported outcomes, included improved sense of safety, better sleep, and reduced anxiety about hypo- and hyperglycemia. Negative outcomes were associated with frequent alarms, calibration problems, and carrying more equipment. With the advent of longer-term trials, more studies are likely to incorporate patient factors relevant to AP acceptance.

A “partial” AP system, the predictive low glucose suspend (PLGS) system (Medtronic, Inc., Northridge, CA), which automatically stops insulin when low BG occurs, is FDA-approved for commercial use. More recently introduced devices have the capacity to suspend insulin when hypoglycemia is predicted by programmed algorithms and to reinitiate insulin delivery when glucose levels recover. Clinical trials have consistently demonstrated that PLGS decreases diurnal and nocturnal hypoglycemia in children and adults, and in hypoglycemic unaware patients (Danne et al., 2011; Ly et al., 2013). Somewhat surprisingly, most PLGS research has not included important patient outcome measures, with only one study demonstrating that it lowers anxiety about nocturnal hypoglycemia (Choudhary et al., 2011).

Information and Communication Technologies

eHealth

eHealth is an umbrella term for a variety of technologies, tools, and applications utilized in the treatment of diabetes, including computer based programs; telemedicine and online counseling; online groups, virtual communities, and social networks; virtual reality and games for health; Internet interventions; and mobile, wireless, and sensor technologies. Although the eHealth field is young, substantial advances have occurred in the past decade and continue at a rapid pace. Today, computers are used in a variety of ways in diabetes treatment—to store and manage clinical data, analyze dietary and glucose data, enable sophisticated decision support algorithms, run insulin management simulations, deliver diabetes education materials, and even provide educational games for children.

Telemedicine

Telemedicine, which utilizes telephone or computer-based video conferencing, enables a one-to-one relationship between clinician and patient, allowing for remote interaction and communication. For online counseling or therapy, clinicians utilize web cams, instant messaging, or chat rooms to conduct synchronous one-on-one sessions. Meta-analyses suggest telemedicine is feasible, but the outcomes have not been overwhelmingly or consistently strong (Farmer, Gibson, Tarassenko, & Neil, 2005). In diabetes, telemedicine has been used in a number of ways; for example, home-based family therapy for adolescents with T1D and T2D and their parents showed a reduction in family conflict after 10 sessions (Harris, Freeman, & Beers, 2009). Telemedicine may be especially important to provide patients living in rural areas with treatment resources usually unavailable, and a recent study from Australia found a high degree of patient satisfaction with videoconferenced consultations with endocrinologists (Fatehi, Martin-Khan, Smith, Russell, & Gray, 2015).

Online Communities

In contrast to this one-to-one relationship, online groups, virtual communities, and social networks use Web-based systems to connect patients, professionals, or both. Groups interact through text, audio, and video using online tools, including blogs, chat rooms, forums, mailing lists, newsgroups, and wikis (Eysenbach, Powell, Englesakis, Rizo, & Stern, 2004). Groups exist for a variety of diabetes communities (e.g., typeoneNation.org), with a specific focus (e.g., typeonenation.org), and are found on social media sites (facebook.com/groups/PEPsquadDRI), or more general support sites (e.g., patientslikeme.com/conditions/322-diabetes-mellitus). Although online groups are popular and widely used, there are little data on either their positive or negative impact (Hilliard, Sparling, Hitchcock, Oser, & Hood, 2015). These authors noted the potential benefits of online communities, including peer support, advocacy, and information transmission, as well as potential risks such as misinformation and privacy concerns. A review of adolescent online communities concluded that, although there can be positive effects, websites would benefit from more guidance and structure to provide positive information that enhances self-management (Ho, O’Connor, & Mulvaney, 2014).

Virtual Reality

Another technology is computer simulated environments, or virtual reality, which has been applied clinically and evaluated for health outcomes in diabetes. For example, a virtual reality self-care program was associated with improvements in body mass index, diabetes-related distress, diet, and physical activity in African American patients with T2D (Ruggiero et al., 2014). Relatedly, there is a small but growing focus on interactive digital game technology (Read & Shortell, 2011) to provide training and education to engage, motivate, model, and positively affect health be-
haviors and outcomes (Rizzo, Lange, Suma, & Bolas, 2011). Games are now being evaluated in research trials, and some positive outcomes have been found, including increases in knowledge, attitude and behavior changes (Baranowski, Buday, Thompson, & Baranowski, 2008; Kato, 2010). Although the potential for adoption of games in diabetes is strong, the clinical trials are often weak and more research is needed to establish gaming as an evidence-based treatment tool.

Internet Interventions

In contrast, development of Internet interventions typically includes psychologists, and is based on evidence-based treatment, such as cognitive–behavioral therapy, to provide behaviorally oriented programs (Ritterband et al., 2003). Often, these interventions are personalized and tailored to the user, and take advantage of the multimedia components available on the web, including high levels of interactivity and graphics, animations, audio, and video. Many also provide follow up and feedback to the user, clinicians, or even family (Ritterband et al., 2003). Research in diabetes-focused Internet interventions over the last decade has been prolific, focusing on both T1D (Cox, Ritterband, Magee, Clarke, & Gonder-Frederick, 2008; van Bastelaar, Pover, Cuijpers, Riper, & Snoek, 2011) and T2D (Tate, Jackvony, & Wing, 2003), pedestrians (Grey, Whitemore, Jeon, Murphy, Faulkner, & Delamater, 2013), older adults (Bond, Burr, Wolf, & Feldt, 2010), and various races and ethnicities (Reininger, Mecca, Stine, Schultz, Ling, & Halpern, 2013). A recent meta-analysis of Internet-delivered programs for diabetes self-management education (DSME) in T2D found overall positive effects compared to usual care (without DSME), but mixed results when compared to other formats for patient education (e.g., face to face; Pereira, Phillips, Johnson, & Vorderstrasse, 2015).

The fastest growing area of eHealth by far is in the mobile and wireless space, also known as mHealth, which utilizes smart phones, wireless devices, and sensors to monitor health status or improve outcomes (Kumar et al., 2013). In 2014, the number of existing mobile applications for diabetes was estimated to be over 650 (Arnhold, Quade, & Kirch, 2014) although the number of actual users appears to be quite small, perhaps less than 2% of the patient population (Wicklund, 2014). Mobile apps tend to focus on BG, food and insulin recording, diabetes self-management, education, coaching, peer support, and games; however, few are evidence-based and there is a significant need for additional research in this area. Because of the exponential growth of medical mobile apps, the FDA has limited their regulatory responsibilities for low-risk apps, and distinguished them from tools for medical diagnosis or treatment (U.S. FDA/Center for Devices and Radiological Health/Center for Biologics Evaluation and Research, 2015). This means that users often have little scientific information to guide their decisions. Clinical trials that do exist have yielded mixed findings (Chomutare, Fernandez-Luque, Arsand, & Hartvigsen, 2011) and it remains unclear whether diabetes-focused mobile applications improve health outcomes and QoL. However, one meta-analysis of 22 studies testing apps for DSME concluded that there is evidence for significant improvements in metabolic control, especially in T2D patients (Liang et al., 2011).

Conclusions and Future Directions

Diabetes self-management has become increasingly technology dependent over the past few decades and diabetes technologies are increasingly complex, advancing now toward fully automated glucose control. Psychosocial and sociotechnical perspectives recognize the interactions between positive patient experience and technology success, and that the greatest barriers to realizing technology’s potential are human factors that limit adoption and effective use. For this reason, psychologists have a critical role to play in the development of: technological devices, data review and patient feedback programs, and skill training and patient support interventions to enhance adoption and use.

One major obstacle is the lagging rate of patient adoption for new diabetes technologies to monitor glucose and deliver insulin, even when there is ample evidence of benefits. While one might argue that mobile apps, which have little to no evidence base, are an exception, the proliferation of available apps has not necessarily been matched by widespread usage by patients. History has shown that the widespread dissemination of most diabetes technology can take decades (see Figure 1), making it important to understand more fully the costs and benefits most important to patients, and other factors that influence motivation and decisions to adopt these technologies. It should be noted also that, ultimately, decreasing barriers to dissemination for state-of-the-art devices depends in large part on technology development itself, and the extent to which problems related to negative patient experiences (limited usefulness, benefits, and convenience) can be overcome through engineering and design.

Along with adoption, long-term, consistent technology use presents challenges, which is especially problematic because achieving clinical benefits depends on high levels of patient usage and engagement. However, even if more patient-friendly devices improve long-term usage, they are not likely to eliminate barriers and burden completely. More research needs to focus on the development of innovative programs, such as those requiring only intermittent technology use to provide clinical benefits while also decreasing the burdens of continuous use (Polonsky et al., 2011; Vigersky, Fonda, Chellappa, Walker, & Ehrhardt, 2012). Another area deserving of more scientific attention is the
leverage of technology to enhance patient education and support, as well as its usefulness to patients in a personally meaningful and reinforcing way. The massive amounts of glucose and insulin data stored in CGM devices and “smart” pumps could be utilized in numerous ways to provide patients with concrete evidence that their behavior matters, and positive reinforcement for making constructive changes (Allen et al., 2008). However, this approach requires software development to integrate and interpret this complex data in a way that is truly useful and applicable to patients, and much more research is needed to identify types of information most likely to enhance diabetes management and control. Current programs, such as CGM feedback graphs, are difficult for many patients to understand and used by only a minority (Wong et al., 2014; Wong et al., 2015).

There is a growing acceptance that a more patient-centered approach is needed in diabetes technology research and an increasing appreciation for the fundamental role of patient experience. However, there is a large gap in our understanding of how to educate and support patients in a way that maximizes the benefits of technology. Evidence-based psychoeducational programs that promote improvements in diabetes self-management and glycemic control can provide a starting point for technology skill training and intervention research (see Hillard, Powell, & Anderson, 2016; and Vendetti, 2016, for reviews of effective psychobehavioral interventions in diabetes). For example, problem-solving therapy is an approach based on cognitive, learning, and social psychology theories, which has well-documented positive effects on self-management (Hill-Briggs et al., 2011). Interventions modeled on this approach could incorporate skill training in dealing with barriers to consistent technology use, as well as the utilization of technology to solve problems in diabetes management. The hope for the future is that the development of diabetes technology will occur more in tandem with the development of psychological and human factor research. This should enhance better integration of diabetes technology in numerous ways, including more widespread, rapid, and nondiscriminatory dissemination, and more consistent use in patients who are receiving the education, support and skill training they need to benefit from technological advances.

References
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