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Review Article

New Digital Health Technologies for Insulin Initiation and Optimization for People With Type 2 Diabetes

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ABSTRACT

Objective: The health and economic burden of type 2 diabetes is of global significance. Many people with type 2 diabetes eventually need insulin to help reduce their risk of serious associated complications. However, barriers to the initiation and/or optimization of insulin expose people with diabetes to sustained hyperglycemia. In this review, we investigated how new and future technologies may provide opportunities to help overcome these barriers to the initiation and/or optimization of insulin.
Methods: A focused literature search of PubMed and key scientific congresses was conducted. Software tools and devices developed to support the initiation and/or optimization of insulin were identified by manually filtering >300 publications and conference abstracts.
Results: Most software tools have been developed for smartphone platforms. At present, published data suggest that the use of these technologies is associated with equivalent or improved glycemic outcomes compared with standard care, with additional benefits such as reduced time burden and improved knowledge of diabetes among health care providers. However, there remains paucity of good-quality evidence. Most new devices to support insulin therapy help track the dose and timing of insulin.
Conclusion: New digital health tools may help to reduce barriers to optimal insulin therapy. An integrated solution that connects glucose monitoring, dose recording, and titration advice as well as records comorbidities and lifestyle factors has the potential to reduce the complexity and burden of treatment and may improve adherence to titration and treatment, resulting in better outcomes for people with diabetes.

Introduction

For people living with type 2 diabetes (T2D), poor glycemic control is associated with the long-term risk of microvascular and macrovascular complications.[1] Although many with T2D and poor glycemic control would benefit from the initiation or intensification of insulin, this is often delayed, causing increased risk.[2,3] Furthermore, adherence to daily insulin for diabetes self-management is challenging.[4]

Barriers to the initiation of insulin are both patient- and physician-related. Both the groups have concerns about its side effects, such as weight gain and hypoglycemia, as well as fears that self-management with insulin is too burdensome. People with diabetes may view the need for insulin as a personal failure and that their quality of life will worsen if insulin is started. Additionally, there may be psychologic barriers to its initiation, such as fears of injections or self-measurement of blood glucose (BG). Physicians may also overestimate patients' concerns or lack of experience in the initiation and timing of insulin.[5] Other important considerations include the cost of insulin, health beliefs based on culture and previous experiences, provider biases regarding the abilities of people with diabetes to safely initiate or intensify their insulin,

Abbreviations: App, application; BG, blood glucose; BI, basal insulin; CGM, continuous glucose monitoring; HCP, health care provider; MDMS, mobile diabetes management system; MITI, Mobile Insulin Titration Intervention; SES, socioeconomic status; T2D, type 2 diabetes.

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including biases based on race and ethnicity, and other social determinants of health.[6] Further, with increasing use of technology to support diabetes care, it is imperative that new strategies are considered to ensure that access to them is equitable and affordable.[7]

Following initiation, barriers to the optimal use of insulin persist. For example, experiencing hypoglycemia early after the initiation of basal insulin (BI) is associated with a higher long-term risk of hypoglycemia or BI discontinuation.[8,9] Clinician concerns about hypoglycemia may result in suboptimal treatment[10] and contribute to many people with T2D not achieving the target glycated hemoglobin (HbA1C) levels.[11] The adjustment of insulin doses in patients with T2D is often led by healthcare providers (HCPs), but access to timely and appropriate HCP resources and education to support effective self-titration remain challenging.[5] Furthermore, poor adherence to an agreed and prescribed insulin regimen is a universal issue, with self-reported adherence rates varying from 43% to 86%.[12] The challenges in adherence and the optimization of insulin may include a busy lifestyle, embarrassment, forgetfulness, and the fear of hypoglycemia.[10]

The described barriers to the optimal use of insulin may explain the disconnect between glycemic outcomes associated with the introduction of BI in clinical trials[13–18] versus that in clinical practice.[11,19] The optimization of titration requires education and understandable communication between HCPs and insulin users regarding the glycemic target and titration regimen. This can be supported by technology.[20] For example, continuous glucose monitoring (CGM) can improve the percentage of time in the target glucose range in adults with T2D compared with usual clinical care.[21]

This review aimed to highlight the challenges in managing the titration and adjustment of insulin in patients with T2D and describe how new and future technologies may help address these unmet needs.

Methods

The articles included in this review were identified using a focused search of PubMed and key congresses. This was not a fully systematic search because additional studies not identified based on the initial search criteria were found during the development of this review and were included for completeness.

The initial search of PubMed was conducted using the following terms: (1) (diabetes[Title/Abstract]) AND (insulin titration [Title/Abstract]), (2) ((diabetes[Title/Abstract]) AND insulin[MeSH Descriptor]) AND digital, (3) (diabetes[Title/Abstract]) AND (smartphone [Title/Abstract]), (4) (diabetes[Title/Abstract]) AND (Digital health technology [Title/Abstract]), (5) (diabetes[Title/Abstract]) AND (smart pen), (6) (diabetes[Title/Abstract]) AND (connected pen), and (7) (diabetes[Title/Abstract]) AND (connected device). In addition, the materials of the following congresses were searched for the terms listed above: Advanced Technologies & Treatments for Diabetes 2020, American Diabetes Association 2019, and International Diabetes Federation 2019. There was no limit on the dates in these searches, and the searches were completed in May 2020.

The results of the searches were manually assessed for the inclusion of a glucose monitoring application (app) or connected glucose monitor, an insulin titration app, an insulin smart (connected) pen, and a decision-support software or algorithm. The results were manually filtered for the exclusion of CGM alone, pump alone, closed-loop systems, nutrition, and/or physical activity apps.

Results and Discussion

The search results included a large number of software-based tools (for use with mobile phones, smartphones, and computers), whereas a limited number of dedicated devices for diabetes management were identified.

Software Tools

Several existing software tools are being offered to support the management of T2D. Overall, these tools have reported equivalent or improved HbA1C levels and hypoglycemic outcomes compared with standard care (Table 1).[22–49]

Reduced Need for Contact With HCPs

The use of 4 tools (LTHome, Mobile Insulin Titration Intervention [MITI], Health2Sync, and the mobile diabetes management system [MDMS]) was associated with a reduced frequency of contact with HCPs needed by participants.

1. LTHome is a web tool that uses an algorithm to provide titration advice for insulin glargine.[33]
2. With MITI, users receive short message service text reminders to provide their fasting BG values, which are reviewed by diabetes nurse educators to inform dose adjustments during weekly phone calls.[34]
3. Health2Sync provides diabetes self-management functionality—such as the logging of BG, with the ability to share this with an HCP—and a chat function facilitating communication between the user and HCP.[35]
4. MDMS consists of a smartphone app and a Bluetooth-enabled glucose meter. The BG levels are automatically uploaded to a clinician portal, which allows the HCP to send messages including about insulin dose recommendations. The insulin user can manually enter their insulin doses and free-text comments with every entry of BG level. In 1 clinical trial, the use of MDMS reduced the time for insulin dose adjustment from 11 minutes with standard management to 5 minutes with the use of the tool.[36]

Improvement in Behavioral Changes

In addition to supporting clinical outcomes and reducing the burden on HCPs, software tools, such as SMS4BG, Welltang, SAED, and patient-centered, smartphone-based, diabetes care systems (PSDCS), may facilitate behavioral changes in people with T2D, including increased knowledge of diabetes[37,38] and improvements in self-care behaviors such as preventative foot care,[39] lifestyle choices,[38,40] and BG monitoring.[40] Furthermore, the ability to record food intake[41] and tag specific behavioral information, such as carbohydrate intake and exercise against glucose measurements,[42] were associated with greater HbA1C level reductions[41,42] and fewer hypoglycemia events.[43]

Integrated Management Tools

Some smartphone apps have integrated several of the diabetes management functions described above into 1 tool with connected devices, such as BG meters, to provide a single platform for use by both patients and HCPs.

Although not identified based on the search criteria, 2 such platforms are Glooko and Social Diabetes, both of which have integrated an app for use by people with diabetes and an HCP

Table 1
Software-Based Technologies Currently Being Evaluated for the Management of Type 2 Diabetes

Tool name	Study population	Key features of intervention	Key outcomes (intervention versus control or baseline)	Hypoglycemia outcomes
Controlled studies				
MITI[34] Levy et al,[34] 2015	Not T1D (n = 61) 1 patient discontinued	Patients texted FBG values every day. A diabetes nurse educator reviewed these weekly and provided dose recommendations based on a titration algorithm. Control: usual care (in-person clinic visits)	HbA1C mean change: −1.90 % versus −1.81 % ($P = .99$) Achievement of study-defined optimal insulin glargine dose: 88% versus 37% ($P < .001$) Median time to optimal dose: 3 versus 7 wk ($P = .007$) Median duration of titration interactions via phone was shorter than that in the clinic MITI patients had more interactions than control (almost all by phone, as opposed to clinic) Lower total costs for copays Patients responded to 84.3% of requests for their blood glucose values Higher treatment satisfaction Patients did not have to attend the clinic as much, saving them time (travel time, wait time, and appointment time compared with that via phone)	3 hypoglycemia events versus 2 in the control group (all mild, no requirement for external assistance)
SAED[37] Alotaibi et al,[37] 2016	T2D (n = 20)	The SAED system consists of mobile patient/HCP support, an intelligent diabetes management component, and a diabetes educational module component. Control: traditional treatment (HCP monitors participant as usual)	HbA1C mean change: −0.91% ($P = .012$) versus 0.07% ($P = .437$) Increased knowledge of diabetes	N/A
LTHome (MyStar WebCoach) (long-acting insulin glargine titration web tool)[33] Bajaj et al,[33] 2016	T2D (n = 139) 19 patients were nonevaluable for primary and alternate efficacy outcomes (13 in intervention arm, 6 in control arm)	Web tool providing advice on insulin titration based on prior insulin doses, resulting FBG, and hypoglycemia Control: enhanced usual therapy (diabetes education program)	HbA1C mean change: −1.0 % versus −1.1 % ($P = .66$) HbA1C ≤7 % target achievement: 20% versus 14% ($P = .36$) Patient satisfaction score improvements were better for the fear of hypoglycemia, diabetes distress score, emotional burden, regimen distress Mean number of additional HCP visits was lower	No difference in hypoglycemia compared to control
DiabetesPal[49] Bee et al,[49] 2016	T2D (n = 66)	Smartphone app that suggests insulin dose based on FBG data containing a hypoglycemia guide, and an additional safety feature (admin module for research staff to monitor and flag issues). Control: paper logbooks and written instructions	HbA1C mean change: no significant difference in reduction between the arms ($P = .26$) Mean insulin doses corrected for body weight were higher Trend toward shorter median time-to-event for reaching maximum dose	No episodes of severe hypoglycemia No change in hypoglycemia versus control
Welltang[38] Zhou et al,[38] 2016	T1D, T2D (intervention: n = 50 [T1D: 10; T2D: 40]; control: n = 50 [8; 42])	Smartphone-based diabetes management app for patients and HCPs. For HCPs, the app provides patient data. For patients, the app comprises 3 components: knowledge (database on diabetes management), self-management (patient-reported data), and communication with HCPs Control: usual standard of care	HbA1C mean change: −1.95% versus −0.79% ($P < .001$) Increased knowledge of diabetes Better self-care behaviors 84% of patients in the Welltang group were satisfied with the app	No difference in hypoglycemic events
Dulce Digital[22] Fortmann et al,[22] 2017	T2D (n = 126) 13 were lost to follow-up (10 in intervention arm, 3 in control arm)	Patients received up to 3 motivational and/or educational calls to action text messages per d over 6 mo. Control: usual care	HbA1C mean change: −1.0 % versus −0.2 % ($P = .03$) Number of blood glucose values texted by patients was a significant predictor of HbA1C at 6 mo High satisfaction and acceptability ratings	N/A
SMS4BG[39] Dobson et al,[39] 2018	T1D, T2D (intervention: n = 183 [T1D: 65; T2D: 118]; control: n = 183 [64; 119]) 7 lost to follow-up (5 in intervention arm, 2 in control arm)	Diabetes self-management support intervention receiving text messages (with information, support, motivation, reminders, for self-management and lifestyle behaviors) for up to 9 mo in addition to usual care Control: usual care	HbA1C mean change: −8.85 mmol/mol versus −3.96 mmol/mol ($P = .007$) Any decrease in HbA1C from baseline: 75% versus 59% of patients ($P = .01$) Improvement in foot care behavior Improvement in overall diabetes support Improvement in health status Improvement on perception of illness identity High levels of satisfaction	N/A

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Table 1 (*continued*)

Tool name	Study population	Key features of intervention	Key outcomes (intervention versus control or baseline)	Hypoglycemia outcomes
Glooko[44] Offringa et al,[44] 2018	T1D, T2D (intervention: n = 899 [T1D: 375; T2D: 285; other/ unknown: 307]; control: n = 900 [T1D: 3; T2D: 15; unknown: 882])	Mobile app containing a digital logbook, user-initiation SMBG data capture, graphical display of data, ability to view stored data and complement these with information on food intake, exercise, medications, and ability to set reminders Control: patients not using the app who uploaded data at their HCP office as part of usual clinical care	Glucose level decrease of 1.8% per mo from 165.0 mg/ dL ($P < .001$), versus increase of 1% per mo from 173.5 mg/dL ($P = .024$) Bigger increase in in-range blood glucose values Increased testing rate versus no change	No change in the probability of hypoglycemia in either group
mDiabetes[23] Kim et al,[23] 2019	T2D (intervention: n = 97; control: n = 94) The full analysis set included 172 patients; 151 completed the 24-wk study	Smartphone-based, patient-centered diabetes care system containing modules for glucose monitoring, physical activity, diet, and a clinical decision-support system Control: paper logbook (with usual way of insulin dose adjustment)	HbA1C reduction of −0.40 versus −0.06 with a difference of adjusted mean change of 0.35% ($P =$ .001) 41.1% versus 20.7% achieved HbA1C <7.0 % ($P = .003$), (for this target without hypoglycemia, this was 31.3% versus 17.1% [$P = .024$]) Patients in the mDiabetes group were more satisfied with their overall health after 24 wk of intervention compared with that at the baseline	Hypoglycemia occurred in 28.0% of patients using mDiabetes and in 29.3% of patients in the control group ($P =$ ns) No severe hypoglycemia in either group
Diabeo-BI, and Interactive voice-response system[24] Franc et al,[24] 2019	T2D (n = 191) A total of 191 were randomized, of which 171 were followed at 4 mo and had HbA1C data available	Mobile app that considers SMBG values and clinician-determined parameters for insulin/carbohydrate ratio, correction factor, and basal insulin dose; a simpler system that provides automatic titration of BI doses via an IVRS Control: standard care	Mean HbA1C change: −1.48% in Diabeo-BI, −1.44% in IVRS versus −0.92% ($P < .002$) HbA1C <7.0 % target achievement: 29.8%, 32.8% versus 12.5% ($P < .02$) FBG target achievement in telemonitoring groups was double that of standard care Insulin doses titrated to a higher level No differences in patient satisfaction	No severe hypoglycemia was reported Mild hypoglycemia frequency similar in all groups
Health2Sync[35] Bramwell et al,[35] 2020	T2D (n = 92) No difference in dropout between the intervention and control arms	Mobile app providing a range of diabetes management and self-management functions, including the logging of BGLs to share with HCPs and a chat function Control: traditional treatment	Mean HbA1C change: −0.85% versus −1% ($P = .75$) Less time required for contact with a credentialed diabetes educator Fewer failure of contact	N/A
Single-arm studies				
DIGS[25] Bergenstal et al,[25] 2012	T2D (n = 26) 8 patients withdrew (6 during the run-in period)	DIGS processed glucose reading and recommended insulin doses on a weekly basis (approval of recommendation before sending to patient) on top of 2 treatment groups: A: T2D with basal-bolus without carbohydrate counting; B: T2D with higher HbA1C to receive biphasic insulin	Mean HbA1C change: −1.1% (A), and −1.2% (B) Decrease in average glucose	Hypoglycemia during the study period was less severe than that in the run-in period[a] Frequency of hypoglycemia in patients with frequent hypoglycemia decreased by 25.2%[a]
OneTouch Reveal (cloud-based web app) + OneTouch Verio blood glucose meter[26] Grady et al,[26] 2016	T2D (n = 17)	Web app that aggregates data from blood glucose meters or insulin pumps and provides analytics to patients/HCPs for treatment and lifestyle decisions	Mean HbA1C change: −0.38% ($P = .09$) Mean blood glucose decreased Strong patient engagement that persisted throughout the study Patients felt motivated to make progress	N/A
PSDCS[40] Kim et al,[40] 2016	T2D (n = 29)	PSDCS consist of a Bluetooth-connected glucometer, a digital food diary, and a wearable physical activity monitoring device	Mean HbA1C change: −0.6% ($P < .0001$) Reduction in HbA1C after 12 wk when glucometer input was at least once a d Reduction in fasting plasma glucose after 12 wk Summary of diabetes self-care activities “general diet,” “exercise,” and “blood glucose testing” had increased after 12 wk	1 case of hypoglycemia resolved by eating
OneDrop|Mobile[41] Osborn et al,[41] 2017	T2D (n = 921)	Mobile app designed to manually and passively store, track, and share data. Users can schedule reminders for medication, set goals, track health outcomes, view statistics, and get data-driven insights	Adjusted for sex, location, diabetes duration, time between entries, and insulin use, HbA1C decreased by 1.27%, from the first (8.16%) to second entry (6.89%) ($P < .001$) Using the app to record food was associated with greater reduction in HbA1C ($P < .05$)	N/A

GlucoTab[27] Aberer et al,[27] 2019	T2D (n = 30)	Mobile decision-support system for diabetes management that incorporates an automated basal-bolus algorithm (in a hospital setting)	Overall mean % of capillary blood glucose in target range (3.9-7.8 mmol/L) was 56.1% TIR was 54.3%, assessed using CGM, and increased over time Mean daily blood glucose improved over time The adherence of physicians in accepting the GlucoTab suggestion for total daily insulin dose was 97.3%	8 hypoglycemic episodes (<3.9 mmol/L) were observed in 5 patients, making up 0.9% of total blood glucose measurements
iSage Rx (iSage)[28] Grdinovac et al,[28] 2019 (conference abstract)	T2D (n = 27)	Mobile phone-based insulin titration app that automatically manages the titration plan; it also provides education on insulin administration	Mean HbA1C change: −0.9% ($P = .002$) In patients with HbA1C >8.0% (mean: 9.3%), this decreased to 7.4% ($P = .005$) Minimal demands on the HCP	Only 1.64% of FBG readings were <70 mg/dL
mySugr[29] Mayer et al,[29] 2019 (conference abstract)	T1D, T2D (n = 61 [T1D: 59%; T2D: 32.8%; other: 8.2%])	Integrated Diabetes Management solution, updated to come with unlimited test strip delivery and certified diabetes educator-led coaching	Estimated HbA1C change: −0.41% ($P < .05$) Mean blood glucose change: −11.8 mg/dL ($P < .05$) Improvement in tests in range (6.8%) ($P < .05$) Improvement in readings above target (−7.2%) ($P < .05$)	N/A
mySugr[46] Hompesch et al,[46] 2018 (conference abstract)	T1D, T2D, other (n = 52 [T1D: 55.8%; T2D: 36.5%; other: 7.7%], 77.1% were on insulin)	Integrated Diabetes Management solution (before 2017 update) in which SMBG data can be uploaded/the app synced with devices; insulin data can also be added manually	Improvement in mean blood glucose (−16 mg/dL, $P < .05$), TIR (+8.5%), readings above target (−8.85%), estimated HbA1C (−0.43 %) and monitoring frequency (+17.75%) Indicated clinically relevant change in estimated HbA1C was achieved by 30.77% of participants	N/A
MDMS[36] Menon et al,[36] 2019	T1D, T2D (n = 20 [T1D: 1; T2D: 19]) 2 participants were lost to follow-up	CDE uses MDMS for insulin dose adjustments that they send to the patient via a text message via the portal (the message may also contain other advice on how to improve glycemic status). Patients use a smartphone with Bluetooth-enabled glucose meter (This study used standard therapy as a control in the same patients who received the intervention, at the same time; standard therapy was a phone call from the CDE as opposed to a text message)	The mean (SD) time for dose adjustment using the intervention was 5.1 (3.1) min versus 11.3 (6.0) min with the standard therapy ($P < .001$) Patients were satisfied, with a high preference for continuing to use the system (scoring 4.7 out of 5) Patients liked the visual representation of data, ease of use, and increased access to HCPs 3 out of the 4 CDEs reported that the use of the MDMS improved their efficiency	N/A
SocialDiabetes[45] Vehi et al,[45] 2019	T1D, T2D (n = 211 [T1D: 144; T2D: 67])	A digital health care platform for diabetes management. It comes with a mobile app and desktop solution for remote monitoring of patients, personalized dose recommendations, charts, reminders, and contact with HCPs	The estimated blood glucose and estimated HbA1C levels were reduced in patients with T1D and in those with T2D (all $P < .001$), independent of the use frequency of the app	
Mobile health APP[30] Cai et al,[30] 2020	T2D (n = 12 530)	Mobile app for education on self-management and the management of insulin treatment. It facilitates communication with HCPs	After 3 mo, HbA1C decreased from baseline (8.33%) by −1.02%, which was maintained at 6 mo After 3 mo, 59% of patients reached HbA1C <7 %, versus 24% at baseline, increasing to 67% at 6 mo ($P < .01$ for both time points) No change in insulin dose over time	N/A
GlucoMe[31] Khanh et al,[31] 2020	Unknown diabetes type (n = 300) 21 patients dropped out (change in internet access [n = 18]; or death [n = 3])	Integrated system of a wireless blood glucose monitor that communicates with a smartphone, a mobile app, and cloud-based software that stores, analyzes, and presents the data	Average glucose decreased from 170.4 mg/dL in the first 2 wk to 150.8 mg/dL in the last 2 wk (wk 11 and wk 12) ($P < .001$) HbA1C declined from 8.3% at baseline to 7.6% at wk 12 ($P < .001$) HCPs felt that the system resulted in improved care, efficiency, and organization of data and recommended using it	N/A
My Dose Coach[47] Unnikrishnan et al,[47] 2020 (conference abstract)	T2D (n = 684)	App with web portal. HCP gives dose recommendations based on FBG and hypoglycemic event data	Mean FBG change: −60.8 mg/dL 43% of participants reached their FBG target Mean time to reach goal: 18.1 d	Average of 1 hypoglycemic event per patient
Dario[43] Hershcovitz et al[43] 2020 (conference abstract)	T1D, T2D (1481 users total [T1D: 363])	Digital diabetes management platform	Number of average level 1 hypoglycemia (<70 mg/dL) events was reduced by 24% and 50% from baseline, after 6 mo and 2 y Number of average level 2 hypoglycemia (<54 mg/dL) events was reduced by 16% and 56% from baseline, after 6 mo and 2 y	N/A

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Table 1 (*continued*)

Tool name	Study population	Key features of intervention	Key outcomes (intervention versus control or baseline)	Hypoglycemia outcomes
Dario[42] Fundoiano-Hershcovitz et al,[42] 2021	T2D (n = 998)	Digital therapeutics platform for chronic diseases. Dario combines an innovative meter (that plugs directly into a smartphone) with a phone app	Improvement in monthly average blood glucose levels during the first 6 mo ($P < .001$), maintained in the following 6 mo ($P = .12$) Patients who "tagged" blood glucose measurements with their behaviors had a better improvement than nontaggers ($P = .03$)	N/A
Studies not on patients				
glUCModel[32] Hidalgo et al,[32] 2014	N/A	Web application for chronic diseases control particularized for diabetes to improve communication/interaction between patients and doctors about personal/medical data. It includes a recommender system, an e-learning course, and a module for automatic generation of glucose levels model	N/A	N/A
PANDIT[48] Simon et al,[48] 2014	T2D (n = 20)	Web-based, computer-assisted insulin self-titration system, assessed in a qualitative study using questionnaires	Patients found that time/effort was reduced while using the automated insulin advice Patients found the system useful if it helped achieve better glycemic control Some patients found lack of personal contact with HCP a drawback	N/A

Abbreviations: app = application; BGL = blood glucose level; BI = basal insulin; CDE = credentialed diabetes educator; CGM = continuous glucose monitoring; DIGS = diabetes insulin guidance system; FBG = fasting blood glucose; HbA1C = glycated hemoglobin A1C; HCP = health care provider; IVRS = interactive voice-response system; MDMS = mobile diabetes management system; MITI = Mobile Insulin Titration Intervention; N/A = not applicable; ns = not significant; PSDCS = patient-centered smartphone-based diabetes care system; SD = standard deviation; SMBG = self-monitoring of blood glucose; T1D = type 1 diabetes; T2D = type 2 diabetes; TIR = time in range.

[a] This study also included a patient group with T1D. The safety results are for all patients, T1D and T2D combined.

dashboard, with additional functionality including synchronization with BG meters or CGM.[44,45] The use of Glooko has shown an increased frequency of BG monitoring, a reduction in hyperglycemic events, and lower average glucose levels.[44] A study investigating the frequency of the use of the Social Diabetes app found that improvements in clinical outcomes were achieved even by infrequent users.[45]

Another platform is mySugr, which integrates self-monitoring of BG data, syncs with devices, and allows for manual entry of insulin data. The use of mySugr is associated with improvements in mean BG levels and a higher monitoring frequency.[46]

Devices

Over time, BG meters have been developed to allow their use in conjunction with other technologies to support decisions regarding diabetes management. Additional technologies have also been developed or are under development to integrate more data into a single device (Table 2).[50–53]

For example, d-Nav is a hand-held device that is used to measure and determine the patterns of BG to automatically determine the appropriate insulin dose. The use of d-Nav in patients with T2D with support from an HCP resulted in superior glycemic control compared with HCP support alone, with no difference in the frequency of hypoglycemic events,[50] and was more cost effective in managing people with diabetes at the risk of developing neuropathic foot ulcers.[51]

Other devices included Insulclock and an electronic pillbox. Insulclock is an electronic system that can be used with multiple types of insulin pens for tracking the date, time of day, dose, type of insulin, temperature, and duration of insulin injections.[52] The electronic pillbox combined with remote home monitoring and HCP involvement showed positive outcomes with regard to glycemic control and participant satisfaction.[53]

Limitations and Barriers to the Implementation of Diabetes Management Technologies

Despite the variety of software and devices available or being investigated for use in diabetes management, there are barriers to the widespread adoption of such tools. Some of these may relate to usability by people with diabetes, the perception of sufficient personal benefit, economics, security, or data privacy. In addition, more data on the effectiveness of new technologies from clinical trials are required to support evidence-based decisions on their use.[54]

Digital access is another consideration for effective implementation of health technologies. In 1 study, <25% of eligible people newly diagnosed with T2D reported that they had received structured education,[55] suggesting that a subset of the population is not served by the current technology and educational materials.

T2D appears to be more prevalent in people of lower socioeconomic status (SES), particularly among migrant groups.[56] Outside of the United States, the prevalence of diabetes in low- and middle-income countries is growing, with 79% of people with diabetes now living in these countries.[57] Diabetes control is poor in these regions, with <30% of patients treated with insulin achieving the glycemic target of <7% (<53 mmol/mol).[58] However, evidence has suggested that people of lower SES do not adopt or use diabetes management technologies to the same extent as people of higher SES.[59] The development of tools for people with diabetes from low- and middle-income backgrounds may require an approach different from that for insulin users with high incomes because of possible differences in the level of education, the knowledge of the disease, and access to new technologies.

Table 2
Device-Based Technologies Currently Being Evaluated for the Management of Type 2 Diabetes

Tool name	Study population	Key features of intervention	Key outcomes (intervention vs control)	Hypoglycemia outcomes
Controlled studies				
d-Nav[50,51] Bergenstal et al,[50] 2019	T2D (n = 181) 13 patients discontinued (6 in the intervention arm, 7 in the control arm)	FDA-approved, hand-held device used to measure glucose, determine glucose patterns, and automatically determine appropriate next insulin dose. Control: HCP support	Mean HbA1C change: −1.0% versus −0.3% ($P <$ .0001) HbA1C <7.0 % target achievement: 21.5% versus 4.5% (P = .0008) HbA1C <8.0 % target achievement: 62.4% versus 33.0% (P = .0001) HbA1C <9.0 % target achievement: 10.8% versus 8.0% (P = .5) Higher final total daily dose	No difference in frequency of hypoglycemic events
d-Nav[50,51] Green et al,[51] 2016	T2D (n = 122)	FDA-approved, hand-held device used to measure glucose, determine glucose patterns, and automatically determine appropriate next insulin dose. Control: current standard care	Mean HbA1C change: from −1.7% versus no change Saved costs and improved QALY in patients at the risk of developing neuropathic foot ulcers	N/A
Single-arm study				
“Diabetes telehealth program”[53] Welch et al,[53] 2015	T2D (n = 30) 5 pillboxes (out of the 28 taken home) were discontinued	Electronic pillbox combined with a remote home monitoring device suite (Bluetooth-enabled blood glucose meter, automatic blood pressure monitor, cellular hub for data upload to clinical application) with HCP involvement	Mean HbA1C change: −0.6% ($P <$ .05) Medication adherence: >80% from wk 2 on Consistently high levels of remote home monitoring High rating for usability High rating for patient satisfaction with the program Improvement in blood glucose control at 3 mo	N/A
Study on device performance				
Insulclock[52] Gomez-Peralta et al,[52] 2019	T1D	Electronic system for tracking date, time of d, dose, type of insulin, temperature, and duration of insulin injections	“Lab test” for the device only, no tests on patients Can detect 7 types of insulin pens Most doses were accurately detected Duration of injection accurately detected Temperature sensor showed high precision	N/A

Abbreviations: FDA = Food and Drug Administration; HbA1C = glycated hemoglobin A1C; HCP = health care provider; N/A = not applicable; QALY = quality-adjusted life year; T1D = type 1 diabetes; T2D = type 2 diabetes.

Considering that the use of mobile phones or smartphones has been increasing in low-income nations, even among older people,[60] the creation of apps for diabetes management for these devices has the potential to improve care in many people with T2D, potentially including those of lower SES, provided that there are resources available for patient education and HCP guidance during their use. However, some users may feel that they do not need an app, do not know about apps, or have not thought about using an app for self-management.[61] More work needs to be done to understand this "app divide" to ensure more equitable access to these types of technologies.

COVID-19

The challenges to the successful implementation of new diabetes management technologies have been an especially pertinent consideration during the current COVID-19 pandemic, which has had a dramatic impact on both emergency and scheduled health care, including care for people with T2D. Diabetes and hyperglycemia are associated with poorer outcomes because of COVID-19,[62,63] making glycemic control even more important during the pandemic. However, although there has been a transition to virtual consultations and telemedicine to facilitate continued care of people with diabetes, the complexities of diabetes management, including the various self-care behaviors required, may limit the effectiveness of current approaches. Nonetheless, the COVID-19 pandemic may offer an opportunity to evaluate the effectiveness of virtual care and telemedicine in patients with T2D and provide insights into how new technologies may help optimize diabetes management and become integrated into standard practice.

Future Developments

In the future, technologies that support improved capturing of data could provide information on which patient populations may be at the risk of events such as hypoglycemia and who could benefit from other digital solutions, data on which are currently lacking. Telehealth, wherein an HCP monitors a patient's health remotely, might be beneficial for some people who use insulin. This might be facilitated by devices that track the date, time of day, temperature, type of insulin used, and duration of injections (as is the case for Insulclock[52]), combined with software that facilitates dose recommendations by an HCP, such as My Dose Coach[47] and MITI.[34]

In order to support adherence to insulin, technologies should include a reminder function that lets users know when they need to take insulin and when they have forgotten their dose. However, advice on insulin dosing should not be based on BG values alone.[48] Diabetes management systems should also integrate data on doses, dose timing, existing comorbidities, lifestyle, and diet and include education on all these aspects to facilitate better outcomes. Two platforms that have already integrated various aspects of diabetes management are Glooko[44] and SocialDiabetes.[45]

To further improve such platforms, Simon et al[48] made recommendations for the design and future implementation of computer-assisted insulin titration systems. First, caregivers should be able to verify that the person with diabetes is willing and able to perform the required tasks and that the person with diabetes should themselves be motivated to initiate and continue using the platform. Patient concerns about lack of contact with their caregiver should be considered while developing new technologies, and options for users to engage more with professionals should be allowed. Finally, to reduce the burden on people with diabetes, the frequency of consulting the system and BG measurements should be decreased when the user reaches the target glucose levels.[48]

Key Features for Tools to Manage T2D

The effective management of T2D requires accurate capturing of data on glucose and insulin dosing as well as patient education and self-management training. However, this represents a significant burden on patients and health care resources.[5,64] New technologies may help alleviate these burdens, for example, by allowing automated transfer of patient data to HCPs. Indeed, some of the tools identified in this review were associated with a reduced time burden in terms of clinic visits and contact with HCPs.[33–36]

To be successful in supporting the management of T2D, several features need to be considered for digital health technologies. Tools should be accessible with respect to not only costs but also the ease of use to minimize challenges related to cognitive ability, health literacy, or manual dexterity. Software should ideally be compatible with all major devices or operating systems, including older models. Additionally, the technology should be secure and should ensure that data cannot be accessed by third parties and devices cannot be hacked.[65] Considering that some people may not have constant internet access, the option to use an app offline would be essential.[49] Evidence has suggested that technology in which people with diabetes can request the involvement of an HCP might be more appealing than those without this feature.[48] Moreover, the data should also be easily accessible to the person with diabetes to facilitate self-management.

To support people with managing their diabetes, the Association of Diabetes Care & Education Specialists has developed advice on 7 key self-care aspects (ADCES7 self-care behaviors) to focus on: healthy coping, healthy eating, being active, monitoring, taking medication, problem solving, and reducing risks.[66] Several key features that have been described in this review that may be considered for an integrated platform are summarized in the Figure and may support the implementation of the ADCES7 self-care behaviors.

Connected Smartpens

Connecting several aspects of diabetes management to a single platform, for instance by integrating modular sensor components (such as glucose sensors and recording devices)[38] to improve data capture and linking health records to diabetes management strategies, could improve future outcomes. Various kinds of pen technologies aim to bring this into practice. For many people with diabetes who use disposable insulin pens, caps that measure the remaining insulin level and/or information on insulin administration can be attached.[67] The Mallya cap is the only device in its category to be designated as a Conformité Européenne medical device, class IIb, and it automatically captures the dose, date, and time of injections and transfers the information to a smartphone app.[68] Recently, the Food and Drug Administration approved the use of insulin smart caps as a part of the Bigfoot Unity diabetes management system for people with diabetes on multiple daily injections, providing support for decisions on insulin doses.[69] The system incorporates smart caps for long- and short-acting insulin pens, a connected smartphone app, and an integrated CGM device.[69]

In contrast to disposable insulin pens, smartpens can measure and store data on the date or time and dose of insulin administered, whereas connected smartpens can send the stored data to a smartphone. To date, there is no pen that provides dose or titration recommendations by itself, without the use of an app.[70]

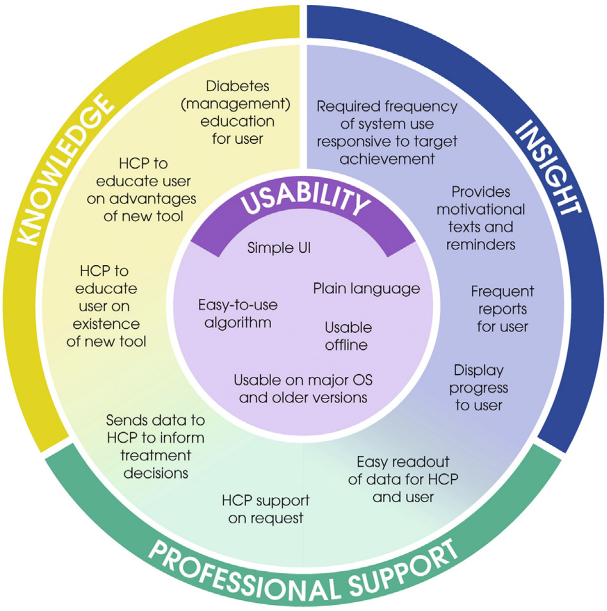

Fig. Key features that may be considered for an integrated platform for insulin management in patients with type 2 diabetes. *HCP* = health care provider; *OS* = operating system; *UI* = user interface.

NovoPen 6 is a connected smartpen developed for patients with T1D that delivers insulin in 1-unit dose increments.[71] It stores data on the timings and units of injections administered, and its use in a single-arm, prospective, observational, proof-of-concept study was shown to significantly increase the time in the target glucose range from baseline to follow-up while reducing missed bolus doses. Various other connected smartpens are available that can record several aspects of insulin and diabetes management, including insulin doses, injection timings, food intake, and activity levels.[67] A novel development is InPen, a connected smartpen that offers several other features, such as reminder alerts, a bolus dose calculator, and integration with CGM devices,[72] and has recently been approved for use in patients with T1D and T2D.

By recording insulin doses alongside other parameters, connected smartpens may help address some of the remaining unmet needs in diabetes management, including freeing up health care resources, improving adherence to insulin therapy and glycemic control, and supporting education on diabetes management (eg, highlighting the connection between insulin use, diet, and exercise when used with CGM).[72] Integrating connected smartpens into a digital platform that both people with diabetes and HCPs can use allows both the parties to monitor treatment and clinical outcomes over time. This may facilitate an ongoing dialog between insulin users and HCPs and empower people with T2D to perform more self-management activities.

Conclusions

In conclusion, people with T2D who use insulin often do not achieve their glycemic targets because of challenges related to adherence and persistence, the fear of side effects, or inconsistent or inadequate approaches to the initiation and titration of insulin and ongoing treatment with insulin. New digital health tools aim to improve patient outcomes by reducing these barriers by, among others features, tracking the time and dose of each administration, providing advice on doses based on glycemic and dose data, delivering reminders, or supporting education on diabetes. The integration of these features into a single platform may facilitate more effective and efficient diabetes care in the future.

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Author Contributions

D.K., S.E., G.V., and K.K. provided comments and input to all drafts of this review, interpretation of the literature, and had responsibility for approving the final version for submission. All authors reviewed and approved the final manuscript.

Disclosure

D.K. is a consultant for Sanofi, Novo Nordisk, and Abbott Diabetes Care; has received research support from Abbott Diabetes Care, Novo Nordisk, and Eli Lilly; and is an advisor to Glooko, SNAQ and Hi.Health. S.E. is a medical advisor for AstraZeneca, BrightSight, InPen, Lexicon, Lilly USA LLC, MannKind, Merck, Novo Nordisk, and Sanofi; is a speaker for AstraZeneca, Lilly USA LLC, MannKind, Merck, and Sanofi; and is an advisory board member for Senseonics and TeamType1. G.V. is a medical consultant at METEDA s.r.l.. K.K. has acted as a consultant and speaker or received grants for investigator-initiated studies from AstraZeneca, Novartis, Novo Nordisk, Sanofi-Aventis, Lilly and Merck Sharp & Dohme, Boehringer Ingelheim, Bayer, Berlin-Chemie AG/Menarini Group, Janssen, and Napp.

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