Chapter

Health Information Technologies in Diabetes Management

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Abstract

About 1 in 11 adults worldwide now have diabetes mellitus, 90% of whom have type 2 diabetes (T2D). Successful glycemic control helps to prevent and reduce complications of T2D, including cardiovascular disease, kidney disease, blindness, neuropathy, and limb amputation, and reduce death related to the disease. However, maintaining optimal glycemic control requires ongoing monitoring and treatment, which can be costly and challenging. To improve diabetes management, the development of innovative self-care strategies is warranted. Advances in health information technologies (HITs) have introduced approaches that support effective and affordable health-care delivery and patient education. Technologies in mobile, computer, e-mail, and Internet approaches have shown evidence in enhancing chronic disease management, suggesting great potential for diabetes management technologies. In this chapter, we provided an overview of the HITs in use for T2D management. We synthesized the latest findings on HITs' effect in reducing HbA1c and managing complications, cardiovascular conditions, in particular. Further, we discussed limitations in the current research in this area and implications for future research. Last, we presented challenges of applying HITs in T2D management in the real-world context and suggested steps to move forward.

Keywords: health information technologies, type 2 diabetes mellitus, glycemic control, HbA1c

1. Introduction

Diabetes is the fastest growing chronic condition worldwide. The prevalence of people with type 2 diabetes (T2D) is growing in each country [1]. Diabetes is also the seventh leading cause of deaths in the world. Around 1.6 million people died due to diabetes in 2016 [1]. Higher blood glucose levels also caused an additional 2.2 million deaths, by increasing the risks of cardiovascular and other complications such as kidney disease, blindness, neuropathy, and limb amputation [2–4]. Successful glycemic control can prevent and reduce these complications. However, to maintain optimal glycemic control requires ongoing monitoring and treatment, which can be costly and challenging [5]. Advances in health information technologies (HITs) have introduced approaches that support effective and affordable health-care delivery and education. Technologies in mobile, computer, e-mail, and Internet approaches have shown evidence in enhancing chronic disease management including diabetes management, via supporting provider decision-making (through electronic risk assessment, alerts, guidelines, formularies, and prescribing) and facilitating patient self-management (through risk communication, Web portals, telemedicine, e-mailing, and secure messaging) [6–8]. In this chapter, we summarized the current findings on HITs in managing T2D, especially on glycemic control and CVD risks management. In addition, we discussed limitations in the current research in this area and implications for future research. Further, we presented challenges of applying HITs in T2D management in the real-world context and suggested steps to move forward.

2. The potential of HITs in chronic disease management

HITs include a broad range of technologies, electronic tools, applications, or systems that provide patient care, information, recommendations, or services for promotion of health and health care [9]. The advantages of using HITs in health care have been well documented [10–13]. They have the potential to empower patients and support a transition from a role in which the patient is the passive recipient of care services to an active role in which the patient is informed, has choices, and is involved in the decision-making process [10]. They are also designed to promote communication and relationships between clinicians and patients and overcome geographical barriers and logistical inconvenience when seeking health-care services [11]. In the realm of chronic disease management, a variety of technologies have shown their positive effects. For examples, electronic health record system provides reminders at the point of care for providers to identify high-priority clinical areas for patients with complex chronic illness [14]; telemonitoring system provides asthma patients with continuous individualized help in the daily routine of asthma self-care [12]; Web-based applications increase knowledge, problem-solving skills, and social support via an interactive system for patients with cancers [13]; mobile technology devices such as personal digital assistants (PDAs) and cellular phones enable additional resources to care and change the location of care; and mobile phone short message service (SMS) were able to remind patients of scheduled visits, deliver test results, and monitor side effects of treatment [15–17]. The HIT-enabled self-care keeps evolving and attempts to address more challenging health-care issues, such as diabetes management where patients need comprehensive information and ongoing guidance as they work to develop a diverse knowledge and skills.

3. HITs in glycemic control among patients with T2D

A growing research attention has been given to evaluate HITs' impact on diabetes management, including the primary management goal, glycemic status, and major complications such as cardiovascular conditions. Previous reviews on this subject suggested that HITs have the potential to improve these disease outcomes [18–23]. However, effect size is specific to the main outcome; glycated hemoglobin (HbA1c) varied between studies with reported mean difference ranging from −0.20 to −0.57% [19–23]. **Table 1** presented the synthesized findings from the latest systematic reviews. Heitkemper et al. searched randomized control trials (RCTs) that studied the effect of HITs on HbA1c among medically underserved patients [21]. In this meta-analysis of 10 eligible trials, HITs were associated with significant HbA1c reduction at 6 months (pooled standardized difference in mean: −0.36, 95% CI −0.53, −0.19) with diminishing but still significant effect at 12 months (pooled standardized difference in mean: −0.27, 95% CI −0.49, −0.04). The authors also performed analyses by HIT type including computer software without Internet

Author, year	Objective and intervention(s) under review	Inclusion criteria	Sample	HbA1c reduction (absolute difference in means)	HbA1c reduction (standardized difference in means and Hedges' g)	CVD risk factor assessment	Intervention period	HIT subgroup analysis	Major limitations
Yoshida et al., 2018 [33]	Evaluating of effect of HITs on T2D glycemic control in general T2D patients, including mobile phone-based HITs, Web-based HITs, short message/text, and other HITs	RCTs conducted from 1946 to December 2017	34 RCTs (40 estimation points); 3983 participants with T2D	−0.65% (95% CI −0.99, −0.64%)	Standard mean difference: −0.57 (95% CI −0.71, −0.43); Hedges' g: −0.56 (95% CI −0.70, −0.43)	A separate analysis focusing on CVD risk factors is upcoming	2–12 months	Mobile phone-based approaches [Hedges' g = −0.66 (95% CI −0.88, −0.45)]; SMS/text [Hedges' g = −0.63 (95% CI −1.07, −0.19)]; Web-based [Hedges' g = −0.48 (95% CI −0.65, −0.30)]	Did not provide analysis at different time points
Heitkemper et al., 2017 [21]	Evaluating of effect of HIT self-management interventions on glycemic control in medically underserved adults with diabetes, including computer software without Internet, cellular/automated telephone, Internet-based HITs, and telemedicine/telehealth	RCTs conducted from 2000 to 2015	10 RCTs; 3257 medically underserved adults with diabetes	Not reported	Standard mean difference: −0.36, 95% CI −0.53, −0.19 at 6 months and −0.27, 95% CI −0.49, −0.04 at 12 months	No	Up to 12 months	Internet-based HITs (standard mean difference = −0.50, 95% CI −0.69, −0.32 at 6 months and −0.87, 95% CI −1.58, −0.21 at 12 months); cellular/automated telephone HITs (standard mean difference = −0.26, 95% CI −0.49, −0.03 at 6 months and not significant at 12 months); telehealth (standard mean difference = −0.37, 95% CI −0.68, −0.06 at 6 months and not significant at 12 months)	External validity issue (only focused on a specific patient group); mixed participants with type 1 and 2 diabetes

Author, year	Objective and intervention(s) under review	Inclusion criteria	Sample	HbA1c reduction (absolute difference in means)	HbA1c reduction (standardized difference in means and Hedges' g)	CVD risk factor assessment	Intervention period	HIT subgroup analysis	Major limitations
Tao et al., 2017 [18]	Evacuating of effect of consumer-oriented HITs in diabetes management	RCTs conducted up until July 2016	18 RCTs; participants in trials ranged from 14 to 1382	Not reported	Standard mean difference: −0.31, 95% CI −0.38, −0.23; glycemic control was significant at intervention duration of 3, 6, 8, 9, 12, 15, 30, and 60 months	No	Up to 60 months	Not reported	Lumped all types of HITs into analysis; mixed participants with type 1 and 2 diabetes
Faruque et al., 2017 [20]	Evaluating of effect of telemedicine on glycemic control, including broad forms of electronic forms communication.	RCTs conducted from 1946 to November 2015	111 RCTs; 23,648 participants with diabetes	−0.57% (95% CI −0.74, −0.40%) at ≥3 months; −0.28% (95% −0.37, −0.20%) at 4–12 months; −0.26% (95% −0.46, −0.06%) at >12 months	Not reported	No	3–68 months	The effect was the greatest in trials where providers used Web portals or text messaging to communicate with patients [mean difference: −0.35% (95% −0.56, −0.14) and −0.28% (95% CI −0.52, −0.14)] at 4–12 months	Mixed participants with type 1 and 2 diabetes
Alharbi et al., 2016 [19]	Evaluating of effect of HITs in glycemic control in T2D patients. HITs included Web-based approaches, telephone-based system, mobile phone-based system, and telemedicine	RCTs conducted up until July 2016	32 RCTs; 40,454 participants with T2D	−0.33%, (95% CI −0.40, −0.26)	Not reported	No	3–36 months	Electronic self-management systems [mean difference: −0.50% (95% CI −0.67, −0.43%)]; EHR [mean difference: −0.33% (95% CI −0.40, −0.26%)]; electronic decision support system [mean difference: −0.15% (95% CI −0.34, −0.16%)]; diabetes registry [mean difference: −0.05% (95% CI −0.15, −0.19%)]	Did not provide analysis at different time points

Author, year	Objective and intervention(s) under review	Inclusion criteria	Sample	HbA1c reduction (absolute difference in means)	HbA1c reduction (standardized difference in means and Hedges' g)	CVD risk factor assessment	Intervention period	HIT subgroup analysis	Major limitations
Pal et al., 2014 [24]	Evaluating computer-based interventions in self-management in T2D patients. Intervention delivered via clinics, the Internet, and mobile phone	RCTs conducted up until November 2011	16 RCTs; 3578 participants with T2D	−0.2% (95% CI −0.4, −0.1%)	Not reported	Yes. Did not find improvement of blood pressure, lipids, or weight due to interventions	8 weeks to 12 months	Mobile phone intervention (mean difference: −0.5%, 95% CI −0.3, −0.7)	Did not provide analysis at different time points
Marcolino et al., 2013 [22]	Evaluating of effect of telemedicine on diabetes care	RCTs conducted up until April 2012	13 RCTs; 4207 participants with diabetes	−0.44% (95% CI −0.61, −0.26%)	Not reported	Yes. Only found telemedicine was associated with reduction in LDL (−6.6 mg/dL, 95% CI −8.3, −4.9 mg/dL)	6–18 months	Not reported	Mixed participants with type 1 and 2 diabetes; did not provide analysis at different time points
Liang et al., 2010 [23]	Evaluating of effect of mobile phone intervention for diabetes on glycemic control	RCTs conducted from January 2010 to February 2010	22 trials including 11 RCTs and 11 non-RCTs; 1657 participants with diabetes	−0.5% (95% CI −0.3, −0.7%)	Not reported	No	3–12 months	Not reported	Lumped nonrandomized and randomized trials together into evaluation

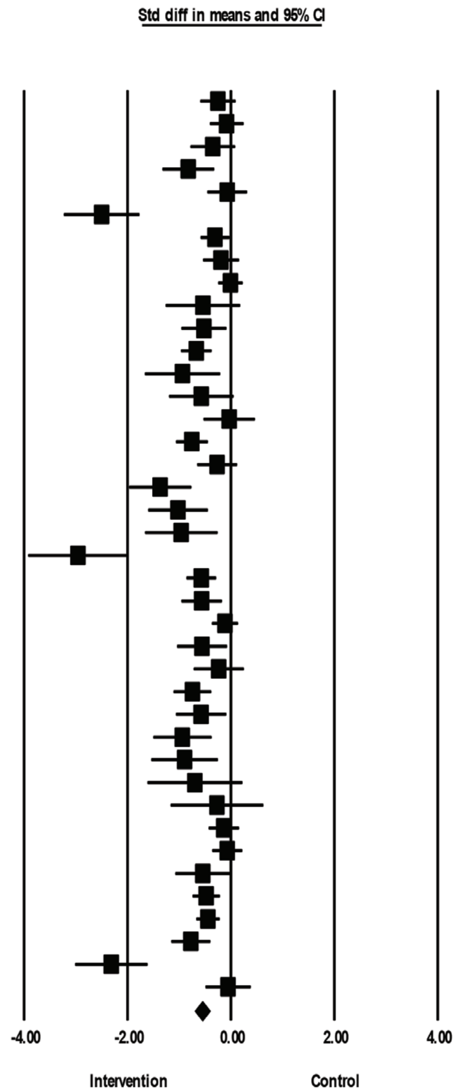
Table 1.
Synthesized findings of effect of HITs on HbA1c and cardiovascular risk factors among diabetes patients.

(n = 2), cellular/automated telephone (n = 4), Internet-based (n = 4), and telemedicine/telehealth (n = 3). The Internet-based interventions demonstrated the greatest reduction in HbA1c at both 6 months (pooled standardized difference in mean: −0.50, 95% CI −0.69, −0.32) and 12 months (pooled standardized difference in mean: −0.87, 95% CI −1.58, −0.21). Cellular and automated telephone interventions showed the smallest reduction. In Tao and colleagues' systematic review on consumer-centered HITs, they identified a significant pooled reduction of −0.31 (95% CI −0.38, −0.23) in HbA1c from 18 RCTs [18]. Similarly, Alharbi et al. also found HITs were associated with a statistically significant reduction in HbA1c levels (mean difference: −0.33%, 95% CI −0.40, −0.26%) [19]. In addition, Alharbi and colleagues found studies focusing on electronic self-management systems demonstrated the greatest reduction in HbA1c (−0.50%), followed by those with electronic medical records (−0.17%), an electronic decision support system (−0.15%), and a diabetes registry (−0.05%) [19]. Faruque et al. identified 11 RCTs with specific focus on effect of telemedicine [20]. Telemedicine refers to the use of telecommunications to deliver health services, expertise, and information on glycemic control [20]. In this study, the authors demonstrated a significant reductions in HbA1c all three follow-up periods (mean difference at ≤3 months: −0.57%, 95% CI −0.74, −0.40%, at 4–12 months: −0.28%, 95% CI −0.37, −0.20%, and at >12 months: −0.26%, 95% CI −0.46, −0.06%). In another meta-analysis that specially focused on telemedicine, Marcolino and colleagues found telemedicine was associated with a statistically significant and clinically relevant decline in HbA1c level compared to control (mean difference = −0.44%, 95% CI −0.61, −0.26%) [22]. Pal et al. examined the effect of computer-based intervention in self-management in adults with T2D. The authors found modest effect associated with the interventions (mean difference: −0.2%, 95% CI −0.4, −0.1%) [24]. Liang et al. assessed the effect of mobile phone intervention on glycemic control in diabetes self-management and found a significant common reduction of HbA1c (mean difference: −0.5%, 95% CI −0.3, −0.7%) among 22 trials over a median follow-up of 6 months [23].

Many of review studies including those mentioned above have shed light on the effect of HITs in glycemic control. However, these studies often included limited number of trials [21], lack of adherence to standard quantitative methods [25], inadequate attention to heterogeneity across studies [26], lumped nonrandomized and randomized trials together into evaluation [19, 23, 25, 27–29], mixed participants with type 1 or type 2 diabetes into analysis [18, 22, 25, 27–29], or restricted searching criteria to a particular patient population or a specific type of HIT [27, 30–32]. To address these limitations and to verify if and how much HITs impact glycemic control, Yoshida and colleagues recently conducted a meta-analysis to examine the most current state of evidence from RCTs concerning the effect of HITs on HbA1c reduction among patients with T2D [33]. From an analysis of 34 eligible studies (40 estimates) identified from multiple databases from January 1946 to December 2017, the study reported that introduction of HITs to standard diabetes treatment resulted in a statistically reduced HbA1c. The absolute mean difference in HbA1c pre- and postintervention between intervention and control group was −0.65% (95% CI −0.99, −0.64%). The pooled reduction (standardized difference in means) of HbA1c was −0.57 (95% CI −0.71, −0.43) (**Figure 1**). In addition, Yoshida et al. also found the reduction was significant across each of the four types of HIT interventions (i.e., mobile phone-based, Web-based technologies, SMS/text, or others) under review, with mobile phone-based approaches generating the largest effects [pooled reduction was −0.67 (95% CI −0.90, −0.45)] followed by SMS/text [−0.64 (95% CI −1.09, −0.19)], and Web-based [−0.48 (95% CI −0.65, −0.30)] [33].

Effect of HITs on HbA1c - Overall

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Agboola, S.; 2016	-0.250	0.179	0.032	-0.601	0.101	-1.397	0.162
Bajaj, H.S.; 2016	-0.082	0.170	0.029	-0.415	0.251	-0.481	0.631
Baron, S.J.; 2017	-0.350	0.225	0.051	-0.792	0.091	-1.555	0.120
Bell, A.M.; 2012	-0.824	0.261	0.068	-1.334	-0.313	-3.162	0.002
Bujnowska-Fedak, M.M.; 2011	-0.071	0.200	0.040	-0.463	0.321	-0.356	0.722
Crowley, M.J.; 2016	-2.500	0.377	0.143	-3.240	-1.760	-6.623	0.000
Dale, J.; 2009, 1a	-0.306	0.147	0.022	-0.594	-0.017	-2.078	0.038
Dale, J.; 2009, 2a	-0.192	0.182	0.033	-0.549	0.165	-1.054	0.292
Dario, C.; 2017	-0.008	0.126	0.016	-0.255	0.238	-0.065	0.948
Faridi, Z.; 2008	-0.542	0.372	0.138	-1.271	0.187	-1.457	0.145
Goodarzi, M.; 2012	-0.522	0.226	0.051	-0.965	-0.078	-2.304	0.021
Harno, K.; 2006	-0.669	0.156	0.024	-0.974	-0.363	-4.290	0.000
Hussein, W.I.; 2011	-0.936	0.376	0.142	-1.673	-0.198	-2.486	0.013
Hsu, W.C.; 2016	-0.572	0.323	0.104	-1.204	0.060	-1.773	0.076
Kardas, P.; 2016	-0.032	0.258	0.067	-0.538	0.474	-0.124	0.901
Kempf, K.; 2017	-0.755	0.161	0.026	-1.070	-0.439	-4.683	0.000
Kim, C.S.; 2010	-0.266	0.201	0.040	-0.660	0.128	-1.325	0.185
Kim, H.S.; 2007, a (3 month)	-1.368	0.311	0.097	-1.978	-0.758	-4.397	0.000
Kim, H.S.; 2007, b (6 month)	-1.024	0.298	0.089	-1.608	-0.440	-3.437	0.001
Kim, H.S.; 2008	-0.960	0.363	0.132	-1.671	-0.249	-2.647	0.008
Kim, S. I & Kim, H.S.; 2008	-2.958	0.497	0.247	-3.931	-1.984	-5.955	0.000
Kim, H.S.; 2016	-0.573	0.151	0.023	-0.869	-0.276	-3.788	0.000
Lim, S.; 2016	-0.566	0.204	0.042	-0.965	-0.166	-2.774	0.006
Pressman, A.R.; 2014	-0.114	0.134	0.018	-0.376	0.148	-0.854	0.393
Quinn, C.C.; 2011, 1a	-0.558	0.252	0.063	-1.051	-0.065	-2.218	0.027
Quinn, C.C.; 2011, 2a	-0.235	0.252	0.064	-0.730	0.259	-0.933	0.351
Quinn, C.C.; 2011, 3a	-0.744	0.191	0.036	-1.117	-0.370	-3.902	0.000
Quinn, C.C.; 2014, 1b (45-64 yr)	-0.575	0.253	0.064	-1.071	-0.080	-2.275	0.023
Quinn, C.C.; 2014, 2b (45-64 yr)	-0.939	0.292	0.086	-1.512	-0.366	-3.211	0.001
Rasmussen, O.W.; 2016	-0.896	0.333	0.111	-1.549	-0.243	-2.688	0.007
Tsang, M.W.; 2001, 1a	-0.697	0.473	0.224	-1.624	0.231	-1.472	0.141
Tsang, M.W.; 2001, 2a	-0.271	0.462	0.213	-1.175	0.634	-0.586	0.558
Trief, P.M.; 2016, 1a	-0.137	0.154	0.024	-0.439	0.164	-0.894	0.371
Trief, P.M.; 2016, 2a	-0.071	0.152	0.023	-0.370	0.227	-0.470	0.639
Waki, K.; 2014	-0.542	0.277	0.077	-1.085	0.001	-1.957	0.050
Wang, G.; 2017	-0.479	0.139	0.019	-0.752	-0.206	-3.438	0.001
Wild, S.H.; 2016	-0.444	0.120	0.014	-0.679	-0.209	-3.699	0.000
Yoo, H.J.; 2009	-0.775	0.197	0.039	-1.161	-0.389	-3.938	0.000
Yoon, K.H.; 2007	-2.314	0.362	0.131	-3.023	-1.605	-6.394	0.000
Zolfaghari, M.; 2012	-0.054	0.228	0.052	-0.501	0.393	-0.237	0.813
	-0.568	0.070	0.005	-0.705	-0.430	-8.104	0.000



Standardized difference in means

Figure 1.
Pooled reduction of HbA1c due to HITs. Adopted from the study of Yoshida et al [33].

HITs also have significant clinical impact in reducing HbA1c among patients with T2D. It is reported that every 1% decrease in HbA1c over a 10-year period is associated with a risk reduction of 21% for diabetes-related death and 37% of microvascular complications [34]. This reduction results from HIT interventions may be bigger than effects of many targeted pharmacological therapies. Oral antidiabetic agents reduced HbA1c levels of 0.5–1.25%, with thiazolidinedione and sulfonylureas showing the best reduction (1–1.25%) [35]. Biguanide reduced HbA1c by 1.0–2.0%; dipeptidyl peptidase 4 (DPP-IV) inhibitor, 0.5–0.8%; GLP-1 agonists, 0.5–1.5%; and TZD, 0.5–1.4% [36]. It is questionable that the effects on HbA1c yielded from the HIT trials were a mixed product of both HITs and standard diabetes care including medication adherence and lifestyle modifications. This concern was addressed in the systematic review of Yoshida et al. [33]. The authors conducted a subset analysis of 18 studies that exclusively compared the outcome between a combined HITs and standard care intervention group vs. standard care control group. The effect size estimated from this analysis was −0.63 (Hedges' g: −0.63 95% CI −0.84, −0.42), which is attributable to HIT tools in addition to the usual care [33]. This result suggests that HITs are the key to the effectiveness rather than tools or components of these trials. Additionally, pharmacotherapies often use motivated patients' sample and they cannot generate their full effects without patients' adherence to treatment and persistence in usage [33]. In this sense, HITs may add additional value in the effectiveness by addressing challenges in adherence of a pharmacological therapy or of behavioral interventions.

4. HITs in managing cardiovascular risks among patients with T2D

T2D is commonly accompanied by cardiovascular complications. Adults with diabetes have a 77–87% prevalence of hypertension, a 74–81% prevalence of elevated low-density lipoprotein cholesterol (LDL), and a 62–67% prevalence of obesity [37]. Cardiovascular disease (CVD) is recognized as the most frequent cause of morbidity and mortality in patients with diabetes, causing up to 70% of all deaths in this patient group [2]. Type 2 diabetes (T2D) confers an approximate twofold elevation of CVD risk, equivalent to that of a previous myocardial infarction [3, 38]. In light of CVD burden in those with diabetes, the management of modifiable CVD risk factors, including hypertension, dyslipidemia, and obesity, is critical to minimizing the risk of macrovascular complications as well as death of diabetes. Yet, the implementation of preventive strategies to CVD among individuals with T2D is often not adequate [39–41] and less than half of patients who visit their care provider meet recommended levels for blood pressure (BP) and lipids [42]. Innovative approaches such as HITs are needed to facilitate CVD risk factor management among patients with T2D.

In the context of cardiovascular care among general populations, HITs were documented to offer numerous benefits and have been associated with improvements in the measurement and monitoring of heart health, including risk factors such as BP, arrhythmia, cholesterol, and weight, as well as the implementation of guideline-based decision support for providers [43]. However, CVD outcomes are usually secondary and less described compared to glycemic status in T2D management trials [26, 44]. Furthermore, many review studies examining HITs' effect in diabetes management often overlooked CVD outcomes [26, 44] or include insufficient sample size or limited CVD parameters for analysis [22, 24]. In the study by Marcolino et al., only 13 studies were included in the final analysis, within which 8 studies assessed the effect on SBP, 7 on DBP, and 5 on LDL [22]. No effects of telecommunication and information technologies were seen on SBP and DBP. They did, however, find a statistically significant reduction on LDL (−6.6 mg/dL, 95% CI −8.3, −4.9 mg/dL) associated with the technologies evaluated. They were not able to perform analysis on weight outcome, because only two studies assessed the effect of HITs on weight and both studies demonstrated a nonsignificant reduction on weight. In the systematic review by Pal et al., among 11 RCTs included in their final analysis, 5 studies looked into changes in BP (only 1 showed improvement in BP), 7 reported changes in BMI or weight (5 were combined in a meta-analysis), and 10 measured serum lipids (7 were combined in a meta-analysis) [24]. The overall pooled effect did not reach statistical significance for all of these outcomes [24].

5. Research limitations and implications

The current research on the effect of HITs in diabetes management has several limitations. First of all, the published trials often do not provide protocols for studies [45]. There is also lack of information on the theoretical bases of the interventions, and whether the HIT interventions are accompanied by other pharmaceutical or lifestyle therapies in their publications. As these HIT interventions are main therapeutic agents, it would be beneficial to explicitly prescribe interventions for trials and state the active components (behavior-change techniques), dose (frequency and intensity of interactions), route (mode of delivery), and duration of treatment [45]. There is also a need to clarify other ingredients in the intervention such as medication, standard care from health professionals, so that the major role of the HITs to the effectiveness of the interventions can be estimated, separating the effects from usual care and treatment [33].

Additionally, intervention periods in published trials are short (most trials under 1 year) [33] and few systematic reviews provided effect estimation by length of follow-up. Studies by Tao et al. and Heitkemper et al. showed that HITs' effect on glycemic control was diminishing as the interventions proceeded [18, 21]. It is not clear whether intervention effect and compliance with the HIT interventions would sustain in the long term. Misuse or nonuse of technological support is a common problem in disease management, which greatly affects patient's outcomes. There is also lack of focus on cardiovascular health assessments in HIT interventions for diabetes management. We only found two systematic reviews that discussed CVD outcomes in addition to glycemic control. Because very few trials included cardiovascular risk factor evaluations, the synthesized findings were modest (**Table 1**). As we discussed earlier, because CVD causes major morbidity and mortality among T2D patients, designing and evaluating HITs for diabetes management should include cardiovascular health indicators. Further, many review studies only reported standardized difference in means [18, 21], which may be less intuitive to patients who care the absolute changes (i.e., mean difference) in outcomes (e.g., HbA1c) due to an intervention. Moreover, it remains unclear whether there are harms associated with the intervention. It has been reported that people may suffer from negative consequences of excessive self-monitoring by finding it uncomfortable, intrusive, and unpleasant [46, 47]. Studies found patients with diabetes who self-monitor their own blood glucose concentration did not benefit from increased glycemic control but rather found their disease more intrusive [48]. The interaction between a HIT device and a patient can be complex, and further studies need to consider these in more detail. Further, whether the interventions would be cost-effective if it required significant health professional support in a long-run has not been documented well in the literature [33, 49]. Additional research with more time points of follow-up is warranted to maximize data to inform the compliance with the HITs, long-term impact on health outcomes, to look for evidence of harms and to determine the cost-effectiveness in the intervention [49]. Studies with CVD risk factor assessments and absolute outcome measurement are also needed.

Moreover, it is unknown which populations will benefit the most from the HIT intervention as the current research in HITs has not always directly engaged diverse end users. There are also many questions surrounding the "digital divide" in HITs use, where the access, usability, and effectiveness of diabetes technologies are divided by users' age, education, computer literacy, culture, and affluence [49]. These issues highlight the importance of engaging more research to design, test, and implement HITs for diverse patients with diabetes.

6. Barriers of using HITs in the real-world context and steps to move forward

While features of HITs can expand patients' ability in diabetes management and the results from the existing research showed their positive effects on outcomes of

HbA1c and CVD risk factors, many of these applications described above have so far been explored predominantly within clinical trials rather than a real-world context. For those that have been widely used in real health-care setting, such as electronic patient record system; both health-care providers and patients have reported difficulties for engagement [50]. Multiple sources of tension contribute to these barriers (**Table 2**).

First of all, the reliability and validity of some HITs is concerning. For example, many manufacturers market their products under the premise that they will help in improving health, but they often do not provide empirical evidence to support the effectiveness of their products [51]. Recent comparisons between different wearable devices for tracking physical activities yielded large heterogeneity in accuracy [52, 53]. The medical apps market also showed the similar discrepancy [54]. Lack of reliability is a serious obstacle that needs to be addressed before a HIT could be considered for medical use. Moreover, whether technological designs incorporated evidence-based guidelines is questionable [55]. It is reported that features of diabetes management apps on the online market did not cover evidence-based recommendations. A recent study evaluated 137 diabetes management apps from two major app stores (iTunes and Google Play) and compared the features with the American Association of Diabetes Educators (AADE) Self-Care Behavior guidelines. The author found an unbalanced feature development of current diabetes management apps. Few apps provided features supporting problem solving, reducing risks, and healthy coping, which are critical for user engagement and successful diabetes self-management [56].

Secondly, the privacy and security of personal data generated by HITs remains problematic. Users of these devices or technologies usually do not own the data; rather, data may be collected and stored by the manufacturers [51]. While some companies are willing to share user's "anonymizing" data via a simple distortion or removal of identifying features, these techniques do not provide adequate levels of anonymity and are not sufficient to prevent identity fraud [57]. Moreover, some devices are easily to be hacked as a result of various communication technologies that aid the transfer of data between the devices and smartphones. It has been reported that wireless digital pacemakers and glucose pumps are vulnerable to cyberattacks [58].

Further, even in relatively widely adopted HIT systems, such as the electronic patient records system, there are still many unfilled promises due to lack of interoperability between systems, difficult-to-use interface, and lack of consideration on patients' backgrounds [50]. In the United States, for example, the patient records

Barriers	Possible solutions
Validity and reliability	• Incorporating empirical evidence into design development • Being coherent with guidelines from credible sources • Evaluating users' needs and improve features on supporting problem solving, reducing risks, and healthy coping
Privacy and security	• Creating regulatory framework and risk-based classifications to promote innovation, protect patient safety, and avoid regulatory duplications
Adaptability	• Building interoperability between systems • Building easy-to-use interface • Providing incentives for engagement • Considering users' diverse background (language, health literacy, cultural preference)

Table 2.
Barriers of using HITs in the real-world context and possible solutions.

systems are not designed to talk to each other [59]. Until now, health-care providers have had little incentive to acquire or develop interoperable systems [50]. As a result, the current electronic health records do not allow a patient or provider to access needed health information anywhere at any time. Additionally, many clinicians are reluctant to invest the considerable time and effort to master difficult-to-use technology, which hindered the anticipated productivity gains of HITs [59]. Moreover, there are limited data collection on patient backgrounds, such as race/ethnicity, language preference, and health literacy in the patient records systems [49]. Lack of this set of data could cause fragmented care delivery and lead to patients' misunderstanding of provider instruction and lose trust in the medical system [49].

To transform HITs a real asset for diabetes care, further steps need to be considered (**Table 2**). First is to create a simple regulatory framework that does not suppress innovation but helps HITs, especially some wearable devices and apps become valid in the context of their health-oriented value [51]. A risk-based classification that promotes innovation, protects patient safety, and avoids regulatory duplications has recently been proposed [60]. As part of this model, the U.S. Food and Drug Administration jurisdiction covers higher-risk medical apps [61]. The National Health Service in the United Kingdom adopts similar pathway with their regulatory framework for mobile apps, which can be classified as "medical devices" by Medicines and Health Products Regulatory Agency [61].

A simple and powerful guide is also needed to transform the HIT system, especially the electronic patient records system. Health data stored in one system should be readily retrievable by others, subject to patient consent [50, 62]. For true interoperability, standardization must be achieved across three dimensions: how messages are sent and received; the structure and format of the information; and terms used within these dimensions [50]. HITs should also facilitate the work of clinicians by providing a system that is intuitive to use and without extensive retraining. Easy-to-use HIT systems not only will increase the productivity of providers but also will be safer [50].

Additionally, HIT systems need to include automated and standardized categories for a patient background (e.g., race/ethnicity, language), facilitate communication among multiple providers and patients, and tailor to the needs of diverse populations [9]. Moreover, a genuine partnership should be fostered between patients and health-care providers through the use of HITs. Engagement can range from patients being simply better informed to individuals themselves being dynamically engaged in the HIT management, giving feedbacks about the HIT interventions, and even controlling who has access to their data [62, 63]. Furthermore, future technologies developed for diabetes management should incorporate balanced features from creditable guidelines to better support changing self-management behaviors of people with diabetes.

7. Conclusion

Overall, the current evidence shows that HITs have favorable impact on glycemic control and CVD risk management among patients with T2D. Future studies should examine the long-term effects of HITs and their cost-effectiveness, potential harms, and test and verify their effectiveness in glycemic control and other important health indicators such as CVD risk factors, among diverse populations. HITs may be valuable tools in enhancing human health and well-being overall. However, their advances also pose challenges in aspects of validity and reliability, patients' privacy, security, and engagement. These issues need to be addressed before a broader implementation of HITs in the real-world setting.

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References

[1] World Health Organization. Global Health Estimates 2016: Disease Burden by Cause, Age, Sex, by Country and by Region, 2000-2016. Geneva: World Health Organization; 2018

[2] Stratmann B, Tschoepe D. Heart in diabetes: Not only a macrovascular disease. Diabetes Care. 2011;**34** (Suppl 2):S138-S144

[3] Haffner SM, Lehto S, Ronnemaa T, Pyorala K, Laakso M. Mortality from coronary heart disease in subjects with type 2 diabetes and in nondiabetic subjects with and without prior myocardial infarction. The New England Journal of Medicine. 1998;**339**(4):229-234

[4] Lorber D. Importance of cardiovascular disease risk management in patients with type 2 diabetes mellitus. Diabetes, Metabolic Syndrome and Obesity. 2014;**7**:169-183

[5] Bujnowska-Fedak MM, Puchala E, Steciwko A. The impact of telehome care on health status and quality of life among patients with diabetes in a primary care setting in Poland. Telemedicine Journal and E-Health. 2011;**17**(3):153-163

[6] Bellazzi R, Arcelloni M, Bensa G, et al. Design, methods, and evaluation directions of a multi-access service for the management of diabetes mellitus patients. Diabetes Technology & Therapeutics. 2003;**5**(4):621-629

[7] Durso SC, Wendel I, Letzt AM, Lefkowitz J, Kaseman DF, Seifert RF. Older adults using cellular telephones for diabetes management: A pilot study. Medsurg Nursing. 2003;**12**(5):313-317

[8] Marchibroda JM. The impact of health information technology on collaborative chronic care management. Journal of Managed Care Pharmacy. 2008;**14**(2 Suppl):S3-S11

[9] Lopez L, Grant RW. Closing the gap: Eliminating health care disparities among Latinos with diabetes using health information technology tools and patient navigators. Journal of Diabetes Science and Technology. 2012;**6**(1):169-176

[10] Demiris G, Afrin LB, Speedie S, et al. Patient-centered applications: Use of information technology to promote disease management and wellness. A white paper by the AMIA knowledge in motion working group. Journal of the American Medical Informatics Association. 2008;**15**(1):8-13

[11] Jimison H, Gorman P, Woods S, et al. Barriers and drivers of health information technology use for the elderly, chronically ill, and underserved. Evidence Report/Technology Assessment. 2008;(175):1-1422

[12] Finkelstein J, O'Connor G, Friedmann RH. Development and implementation of the home asthma telemonitoring (HAT) system to facilitate asthma self-care. Studies in Health Technology and Informatics. 2001;**84**(Pt 1):810-814

[13] McTavish FM, Gustafson DH, Owens BH, et al. CHESS: An interactive computer system for women with breast cancer piloted with an under-served population. Proceedings of the Annual Symposium on Computer Applications in Medical Care. 1994:599-603. PMID: 7949998

[14] Veinot TC, Zheng K, Lowery JC, Souden M, Keith R. Using electronic health record Systems in diabetes care: Emerging practices. IHI. 2010;**2010**:240-249

[15] Milne RG, Horne M, Torsney B. SMS reminders in the UK national health service: An evaluation of its impact on "no-shows" at hospital out-patient clinics. Health Care Management Review. 2006;**31**(2):130-136

[16] Chung P, Yu T, Scheinfeld N. Using cellphones for teledermatology, a preliminary study. Dermatology Online Journal. 2007;**13**(3):2

[17] Weaver A, Young AM, Rowntree J, et al. Application of mobile phone technology for managing chemotherapy-associated side-effects. Annals of Oncology. 2007;**18**(11):1887-1892

[18] Tao D, Wang T, Wang T, Liu S, Qu X. Effects of consumer-oriented health information technologies in diabetes management over time: A systematic review and meta-analysis of randomized controlled trials. Journal of the American Medical Informatics Association. 2017;**24**(5):1014-1023

[19] Alharbi NS, Alsubki N, Jones S, Khunti K, Munro N, de Lusignan S. Impact of information technology-based interventions for type 2 diabetes mellitus on glycemic control: A systematic review and meta-analysis. Journal of Medical Internet Research. 2016;**18**(11):e310

[20] Faruque LI, Wiebe N, Ehteshami-Afshar A, et al. Effect of telemedicine on glycated hemoglobin in diabetes: A systematic review and meta-analysis of randomized trials. CMAJ. 2017;**189**(9):E341-E364

[21] Heitkemper EM, Mamykina L, Travers J, Smaldone A. Do health information technology self-management interventions improve glycemic control in medically underserved adults with diabetes? A systematic review and meta-analysis. Journal of the American Medical Informatics Association. 2017;**24**(5):1024-1035

[22] Marcolino MS, Maia JX, Alkmim MB, Boersma E, Ribeiro AL. Telemedicine application in the care of diabetes patients: Systematic review and meta-analysis. PLOS One. 2013;**8**(11):e79246

[23] Liang X, Wang Q, Yang X, et al. Effect of mobile phone intervention for diabetes on glycaemic control: A meta-analysis. Diabetic Medicine. 2011;**28**(4):455-463

[24] Pal K, Eastwood SV, Michie S, et al. Computer-based interventions to improve self-management in adults with type 2 diabetes: A systematic review and meta-analysis. Diabetes Care. 2014;**37**(6):1759-1766

[25] Costa BM, Fitzgerald KJ, Jones KM, Dunning Am T. Effectiveness of IT-based diabetes management interventions: A review of the literature. BMC Family Practice. 2009;**10**:72

[26] Rasekaba TM, Furler J, Blackberry I, Tacey M, Gray K, Lim K. Telemedicine interventions for gestational diabetes mellitus: A systematic review and meta-analysis. Diabetes Research and Clinical Practice. 2015;**110**(1):1-9

[27] Adaji A, Schattner P, Jones K. The use of information technology to enhance diabetes management in primary care: A literature review. Informatics in Primary Care. 2008;**16**(3):229-237

[28] Baron J, McBain H, Newman S. The impact of mobile monitoring technologies on glycosylated hemoglobin in diabetes: A systematic review. Journal of Diabetes Science and Technology. 2012;**6**(5):1185-1196

[29] Jaana M, Pare G. Home telemonitoring of patients with

diabetes: A systematic assessment of observed effects. Journal of Evaluation in Clinical Practice. 2007;**13**(2):242-253

[30] Marcolino AM, Barbosa RI, das Neves LM, Mazzer N, de Jesus Guirro RR, de Cassia Registro Fonseca M. Assessment of functional recovery of sciatic nerve in rats submitted to low-level laser therapy with different fluences. An experimental study: Laser in functional recovery in rats. Journal of Hand and Microsurgery. 2013;**5**(2):49-53

[31] Polisena J, Tran K, Cimon K, Hutton B, McGill S, Palmer K. Home telehealth for diabetes management: A systematic review and meta-analysis. Diabetes, Obesity & Metabolism. 2009;**11**(10):913-930

[32] Ramadas A, Quek KF, Chan CK, Oldenburg B. Web-based interventions for the management of type 2 diabetes mellitus: A systematic review of recent evidence. International Journal of Medical Informatics. 2011;**80**(6):389-405

[33] Yoshida Y, Boren SA, Soares J, et al. Current Diabetes Reports. 2018;**18**:130. https://doi.org/10.1007/s11892-018-1105-2

[34] Srimanunthiphol J, Beddow R, Arakaki R. A review of the United Kingdom prospective diabetes study (UKPDS) and a discussion of the implications for patient care. Hawaii Medical Journal. 2000;**59**(7):295, 313-298

[35] Sherifali D, Nerenberg K, Pullenayegum E, Cheng JE, Gerstein HC. The effect of oral antidiabetic agents on A1C levels: A systematic review and meta-analysis. Diabetes Care. 2010;**33**(8):1859-1864

[36] Choudhary P, Amiel SA. The use of technology to reduce hypoglycemia. Pediatric Endocrinology Reviews. 2010;**7**(Suppl 3):384-395

[37] Preis SR, Pencina MJ, Hwang SJ, et al. Trends in cardiovascular disease risk factors in individuals with and without diabetes mellitus in the Framingham heart study. Circulation. 2009;**120**(3):212-220

[38] Juutilainen A, Lehto S, Ronnemaa T, Pyorala K, Laakso M. Type 2 diabetes as a "coronary heart disease equivalent": An 18-year prospective population-based study in Finnish subjects. Diabetes Care. 2005;**28**(12):2901-2907

[39] Joseph J, Svartberg J, Njolstad I, Schirmer H. Change in cardiovascular risk factors in relation to diabetes status: The Tromso study. European Journal of Preventive Cardiology. 2012;**19**(3):551-557

[40] Saydah SH, Fradkin J, Cowie CC. Poor control of risk factors for vascular disease among adults with previously diagnosed diabetes. Journal of the American Medical Association. 2004;**291**(3):335-342

[41] Farkouh ME, Boden WE, Bittner V, et al. Risk factor control for coronary artery disease secondary prevention in large randomized trials. Journal of the American College of Cardiology. 2013;**61**(15):1607-1615

[42] Sieverdes JC, Treiber F, Jenkins C. Improving diabetes management with mobile health technology. The American Journal of the Medical Sciences. 2013;**345**(4):289-295

[43] eHealth Intiative. An Issue Brief on Health Information Technology and Cardiac Care; 2013

[44] Su D, Zhou J, Kelley MS, et al. Does telemedicine improve treatment outcomes for diabetes? A meta-analysis of results from 55 randomized controlled trials. Diabetes Research and Clinical Practice. 2016;**116**:136-148

[45] Pal K, Eastwood SV, Michie S, et al. Computer-based diabetes

self-management interventions for adults with type 2 diabetes mellitus. Cochrane Database of Systematic Reviews. 2013;**3**:CD008776

[46] Krantz DS, Baum A, Wideman M. Assessment of preferences for self-treatment and information in health care. Journal of Personality and Social Psychology. 1980;**39**(5):977-990

[47] Goyder C, McPherson A, Glasziou P. Diagnosis in general practice. Self diagnosis. BMJ. 2009;**339**:b4418

[48] O'Kane MJ, Bunting B, Copeland M, Coates VE, Es Group. Efficacy of self monitoring of blood glucose in patients with newly diagnosed type 2 diabetes (ESMON study): Randomised controlled trial. BMJ. 2008;**336**(7654):1174-1177

[49] Lopez L, Green AR, Tan-McGrory A, King R, Betancourt JR. Bridging the digital divide in health care: The role of health information technology in addressing racial and ethnic disparities. Joint Commission Journal on Quality and Patient Safety. 2011;**37**(10):437-445

[50] Kellermann AL, Jones SS. What it will take to achieve the as-yet-unfulfilled promises of health information technology. Health Affairs. 2013;**32**(1):63-68

[51] Piwek L, Ellis DA, Andrews S, Joinson A. The rise of consumer health wearables: Promises and barriers. PLoS Medicine. 2016;**13**(2):e1001953

[52] Lee JM, Kim Y, Welk GJ. Validity of consumer-based physical activity monitors. Medicine and Science in Sports and Exercise. 2014;**46**(9):1840-1848

[53] Case MA, Burwick HA, Volpp KG, Patel MS. Accuracy of smartphone applications and wearable devices for tracking physical activity data. Journal of the American Medical Association. 2015;**313**(6):625-626

[54] Wolf JA, Moreau JF, Akilov O, et al. Diagnostic inaccuracy of smartphone applications for melanoma detection. JAMA Dermatology. 2013;**149**(4):422-426

[55] Chomutare T, Fernandez-Luque L, Arsand E, Hartvigsen G. Features of mobile diabetes applications: Review of the literature and analysis of current applications compared against evidence-based guidelines. Journal of Medical Internet Research. 2011;**13**(3):e65

[56] Ye Q, Khan U, Boren SA, Simoes EJ, Kim MS. An analysis of diabetes mobile applications features compared to AADE7: Addressing self-management behaviors in people with diabetes. Journal of Diabetes Science and Technology. 2018;**12**(4):808-816

[57] Kosinski M, Stillwell D, Graepel T. Private traits and attributes are predictable from digital records of human behavior. Proceedings of the National Academy of Sciences of the United States of America. 2013;**110**(15):5802-5805

[58] Maisel WH, Kohno T. Improving the security and privacy of implantable medical devices. The New England Journal of Medicine. 2010;**362**(13):1164-1166

[59] O'Malley AS, Grossman JM, Cohen GR, Kemper NM, Pham HH. Are electronic medical records helpful for care coordination? Experiences of physician practices. Journal of General Internal Medicine. 2010;**25**(3):177-185

[60] Cortez NG, Cohen IG, Kesselheim AS. FDA regulation of mobile health technologies. The New England Journal of Medicine. 2014;**371**(4):372-379

[61] McCartney M. How do we know whether medical apps work? BMJ. 2013;**346**:f1811

[62] Kreitmair KV, Cho MK, Magnus DC. Consent and engagement, security, and authentic living using wearable and mobile health technology. Nature Biotechnology. 2017;**35**(7):617-620

[63] Wilbanks J, Friend SH. First, design for data sharing. Nature Biotechnology. 2016;**34**(4):377-379