Review.

Effectiveness of Smartphone-Based Self-Management Interventions on Self-care and Health Relevant Outcomes in Patients with Type 2 Diabetes: A Systematic Review and Meta-analysis

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Abstract

Background: Type 2 Diabetes Mellitus (T2DM) is a major health problem worldwide. Proper self-management can improve health outcomes and reduces risk of diabetic complications. Recently, smartphone-based technology has been used for self-management programs but their effectiveness in improving self-efficacy, self-care activities, health-related quality of life (HRQoL) and clinical outcomes for patients with T2DM is not well understood.

Objectives: To review the evidence and determine the effectiveness of smartphone-based self-management interventions on self-efficacy, self-care activities, HRQoL, glycated haemoglobin (HbA1c), body mass index (BMI), blood pressure (BP) levels of adults with T2DM.

Methods: A systematic search of five databases (PubMed, Embase, Cochrane, CINAHL and Scopus) was conducted. Study published in English, from January 2007 to January 2018, were considered. Only randomised controlled trials (RCTs) of smartphone-based self-management interventions for patients with T2DM that reported any of the study outcomes were included. Two reviewers independently screened the studies, extracted data and assessed the quality of the studies. Meta-analyses were conducted for the different study outcomes.

Results: A total of 26 articles, consisting of 22 studies with 2645 participants were included in the review. A meta-analysis conducted on self-efficacy revealed a large improvement of 0.98 (95% confidence interval [CI] 0.42 to 1.55; \( P < 0.001 \)) with smartphone-based self-management interventions. The effect size on self-care activities was also large (\( d = 0.90; 95\% \text{ CI 0.24 to 1.57;} P = 0.001 \)). Significant heterogeneity was present among studies pooled for both outcomes and subgroup analyses were conducted for self-efficacy. Smartphone-based self-management interventions also gave a small improvement on HRQoL (\( d = 0.26; 95\% \text{ CI 0.06 to 0.47;} P = .01 \)) and a significant reduction in HbA1c (pooled MD = -0.55; 95% CI -0.60 to -0.40; \( P < 0.001 \)). The effects on BMI and BP were not statistically significant.

Conclusions: Smartphone-based self-management interventions appear to have beneficial effects on self-efficacy, self-care activities and health-relevant outcomes for patients with T2DM. However, more research with good study designs is needed to evaluate the effectiveness of smartphone-based self-care interventions for T2DM.
Introduction

Diabetes is a major health problem worldwide due to its rapidly growing prevalence and high disease burden. It is a major cause of blindness, kidney failure, heart attacks, stroke and lower limb amputation [1]. World Health Organization (WHO) projects that diabetes will be the seventh leading cause of death in 2030[2]. In 2014, the WHO estimated that there were 422 million adults living with diabetes compared to 108 million in 1980[3]. This rapid growth in the prevalence of diabetes is present in both developing and developed countries [4]. Hence, a high economic burden is expected, with diabetes accounting for 10.8% of the total health expenditure worldwide [5]. Risk factors of T2DM can be divided into non-modifiable and modifiable risk factors. Modifiable risk factors of T2DM are overweight, obesity, physical inactivity, high intake of carbohydrates, processed sugar and fat in diet and active smoking [6-9].

Diabetes can be managed and treated with good self-management, which could lead to more than 0.4 % reduction in glycated hemoglobin (HbA1c) of type 2 diabetes patients, more than 5 mg/dl reduction in total cholesterol, and more than 1 mmol/L reduction in fasting blood glucose [10-15]. Traditionally, self-management support for diabetic patients comprised of face-to-face patient education using printed materials, demonstrations or video [16]. Follow-ups in the outpatient or primary health clinic are used to reinforce education or assess for complications [3]. However, the majority of patients with diabetes continue to have low adherence to self-care activities and related health outcomes which indicate that such measures are not sufficient in supporting them in managing their condition [17]. In order to improve this, self-management programs for T2DM are also available through smartphone technologies [18]. Smartphone-based self-management interventions have been found to improve health outcomes in chronic diseases and potentially play a crucial role in supporting self-care activities for T2DM [18]. They are defined as smartphone-based technologies designed to assist patients in their diabetes self-care activities, allowing patients to be actively engaged and take responsibility for their own actions [19]. This can be done through education on diabetes and self-care activities, self-monitoring of symptoms along with the provision of feedback and/or regular reminders to carry out self-care activities [20-22].

There were nine systematic reviews on smartphone-based interventions for patients with diabetes [18, 23-30]. However, existing reviews were not able to evaluate the effectiveness of
smartphone-based technologies on the outcomes of interest in this review, namely self-efficacy, self-care activities, HRQoL and clinical outcomes. As self-efficacy, self-care activities and HRQoL are also important in achieving successful management of T2DM, there is a need to quantitatively analyse evidence on these outcomes along with clinical outcomes [31]. As such, current review aims to determine the effectiveness of smartphone-based interventions that have self-management components on improving self-efficacy, self-care activities, HRQoL and clinical outcomes in patients with T2DM. The evidences synthesized can then be used to help guide future research and clinical practice in the management of T2DM.

Methods
The study followed the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guideline (Figure 1).

Search strategy
Five databases were chosen to be used in the searching process: PubMed, Embase, Cochrane Central Register of Controlled Trials, CINAHL and Scopus. Only randomised controlled trials (RCTs) between January 2007 to January 2018 and in the English language were included in this review. Extensive search strategies were developed in collaboration with an experienced librarian. A three-step search strategy was employed. The initial phase included a search using the keywords and Medical Subject Headings (MeSH) terms “type 2 diabetes”, “smartphone”, “cell phone” in PubMed. This was to generate and compile a list of keywords and MeSH terms that would be used in the second stage of the search to ensure that all relevant studies will not be missed.

Secondly, the compiled list of keywords and MeSH terms was used to search the five databases. The index terms and keywords of a specific concept were combined using the boolean operator “OR” while the differing concepts of “smartphone-based interventions” and “type 2 diabetes mellitus” were then searched together using the boolean operator “AND”. The search in five databases is shown in Multimedia Appendix 1.

The third phase involved a search for unpublished trials from ProQuest Dissertations and Theses Global, the most comprehensive database for graduate research. The reference lists of the eligible studies and relevant systematic reviews of the topic were hand searched to identify additional studies for screening.
Eligibility Criteria
We included studies that were randomized controlled trials (RCTs), which met the following inclusion criteria: 1) Study participants were adult patients who were age 18 years old and above with a confirmed diagnosis of T2DM. 2) Studies evaluated the effectiveness of the Smartphone-based self-management interventions on mobile phones including but not limited to text messages, and Smartphone applications. 3) Studies separated participants into at least one group receiving smartphone-based self-management interventions and one group receiving usual care or with no smartphone-based intervention. 4) Studies that explored at least one of the following outcomes: self-efficacy, self-care activities, HRQoL and/or clinical outcomes, such as HbA1c, body mass index (BMI), blood pressure.

We excluded studies that used qualitative data as an outcome measure, not written in English, and the use of smartphone-based technology was not for diabetes self-management purpose.

Study Selection
The results of the systematic searches were imported to a reference manager, ENDNOTE software. Duplicates were removed using the software and also by hand. Then, two reviewers (HA and YJ) independently screened titles and abstracts of studies and categorized them into those that meet, potentially meet or do not meet the eligibility criteria. Studies with titles and abstracts deemed irrelevant and did not meet the eligibility criteria were thus removed. The full-text of those that met or could potentially meet the eligibility criteria were retrieved and HA and YJ independently screened the full-texts.

Data Extraction
Data from the included studies were extracted independently two researchers using a standardized data extraction form from The Cochrane Handbook for Systematic Reviews of Interventions [32]. The form included report details (authors, year and country), methods (study design, dates and total duration of study), participants (sample size, gender, age range, mean age, and participant eligibility criteria), intervention (content of intervention, provider, and duration that intervention was administered), and outcome measures (instruments or tools used and key outcome findings from the study). After extracting the data independently, the two researchers compared their data extraction forms to maintain comprehensiveness and accuracy of the data collected. The summary of the included studies can be found in Multimedia Appendix 2.
Assessment of Risk of Bias

Risk of bias for each study was assessed by two researchers independently using the Risk of bias tool outlined in the Cochrane Handbook for Systematic Reviews of Interventions [32]. The two reviewers settled any disparities by consulting the third independent reviewer (WW).

Data Syntheses and Analyses

Data was synthesised using RevMan version 5.3.5, according to statistical guidelines defined in the Cochrane Handbook for Systematic Reviews of Interventions [32]. Continuous data were analyzed using the inverse variance (IV) approach by combining the mean difference (MD) or the standardised mean difference (SMD) of individual studies. The overall effect was assessed as Cohen’s $d$. The significance level was set at $p < 0.05$.

Heterogeneity was estimated using Cochran’s $Q$ test and $I^2$ statistics. The statistical significance of heterogeneity was set at $p < 0.10$ and the degree of variability was estimated through $I^2$ values, with 75%, 50%, 25%, or 0% indicating high, moderate, low, or no heterogeneity, respectively [33]. The fixed-effects model was used in the absences of any significant heterogeneity ($p$-value of $Q$-test $> 0.10$ and $I^2$ value $<50\%$), while random effects model was used if heterogeneity was significant ($p$-value of $Q$-test $<0.10$ and $I^2$ value above 50% value but below 75%) [34]. In addition, subgroup analyses were done to identify the causes of heterogeneity when substantial heterogeneity ($I^2 \geq 75\%$ and $p < 0.10$) was found.

Results

Studies Identification

The systematic search process is illustrated in the PRISMA Flow Diagram in Figure 1. A total of 1697 studies were identified. Through screening the references of past similar SRs, two more studies were found. Nine hundred and forty six duplicates were removed using the software and manually by the main reviewer (HA). Fifteen studies that were published before the year 2007 were also removed. This resulted in 738 articles left for screening of their title and abstracts. Two hundred and sixty four records were excluded based on their titles and 207 records excluded based on study abstracts because they did not meet the eligible criteria.

The full texts were retrieved for the remaining 267 records. Two independent researchers then critically reviewed the full-text articles against the eligibility criteria, among which, 241 articles were excluded as they did not meet the inclusion criteria for various reasons as shown in Figure 1. In total, 26 articles (consisting of 22 studies) were identified as eligible for the review.
Records identified through database searching:
- PubMed: 370
- Cochrane: 268
- Embase: 414
- CINAHL: 248
- Scopus: 397
Total: n=1697

Studies excluded:
- Before year 2007 (n=15)
- Duplicates (n=946)

Studies excluded:
- Irrelevant based on title (n=264)
- Irrelevant based on abstract (n=207)

Full-text articles excluded: n = 241
- Abstract (n=55)
- Not RCT (n=49)
- Telephone calls (n=32)
- No smartphone used (n=27)
- Intervention had no self-management component (n=15)
- Computer-based interventions (n=11)
- Did not separate results for T2DM patients (n=10)
- Home teledevice only (n=8)
- Teleconferencing only (n=7)
- Did not measure interested outcomes (n=6)
- Not published in English (n=5)
- Self-management component not done through smartphone (n=3)
- Web-based intervention (n=3)
- Participants did not have T2DM (n=3)
- Intervention was for physicians (n=2)
- Control group also used smartphone-based intervention (n=2)
- Intervention was for titrating medications (n=1)
- Conference paper (n=1)
- Intervention was for nurses (n=1)

Studies excluded from meta-analysis:
- Insufficient data (n=4)

Studies included in the review:
- n = 22 (26 reports)

Studies included:
- n = 18
Description of Included Studies

The total sample size analysed across all 26 articles (consisting of 22 studies) is 2645 participants (males = 1169, females = 1242), with sample sizes ranging from 26 to 301 participants. It did not report the proportion of male and female participants in Shetty’s study [35]. The mean ages of the participants varied between 47.5 to 65.8 years old (mean = 53.5, SD = 4.5), excluding one study which reported age in categories [36]. The studies were conducted across countries: United States of America (n = 6) [36-41], South Korea (n = 3) [42-44], India (n = 2) [35,45], Iran (n = 2) [46,47], Bangladesh (n = 1) [48], China (n = 1) [49], Democratic Republic of Congo (n = 1) [50], Finland (n = 1) [51], Japan (n = 1)[52], Mexico (n = 1) [53], Norway (n = 1) [54], Philippines (n = 1) [55], and Thailand (n = 1) [56].

Risk of Bias

The risk of bias summary is presented in Figure 2. 16 studies (72.7%) were rated low risk of selection bias for random sequence generation. Only four studies (18.2%) used opaque envelops or a third party for allocation concealment and was rated low risk of bias. In general, 10 studies (45.5%) were rated unclear risk of bias due to insufficient information on blinding of participants or personnel. The rest of the studies (n = 12, 54.5%) were rated as high risk of bias as the participants and/or personnel were not blinded. For detection bias, three studies (13.6%) were rated as low risk as outcome assessors were blinded. In addition, four studies reported attrition rates of more than 20% but performed ITT analysis and explained reasons for high attrition. Six studies (27.3%) did had attrition rates of less than 20% and explained the reasons for attrition. One study reported 0% attrition at the end of the study and was rated low risk of bias. Five of the studies (22.7%) had published a protocol and reported all pre-specified outcomes have been reported in the pre-specified way and were rated as low risk of reporting bias. Four studies (18.2%) were rated as high risk of bias as they had a published protocol but failed to report all of the pre-specified outcomes.
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**Description of the Interventions**

The studies included in our review could be categorised into four main types: ‘education’ (provision of diabetes-related and self-care education), ‘reminders’ (reminders to carry out specified self-care activities), ‘self-monitoring’ (monitoring and recording of self-care data obtained) and ‘feedback’ (provision of feedback or healthcare recommendations based on the self-care data input either by healthcare professionals or pre-designed algorithm software). Majority of the included studies used a combination of T2DM self-management intervention components except for three studies that only provided education. In addition, twelve studies delivered regular diabetes-related SMSes as the intervention at varying frequencies of twice a day ($n = 2$), daily ($n = 5$), 4 per week ($n = 1$), 3 per week ($n = 1$), once in 3 days ($n = 1$), weekly ($n = 1$) and monthly ($n = 1$). Nine studies (40.1%) used smartphone applications interventions. One study used both a smartphone application and regular SMSes as its intervention.

**Effectiveness of Interventions on Self-efficacy**

Six studies measured self-efficacy using different self-reported tools. One study used the Spanish Self-efficacy tool [53], which is a self-report measure with reported adequate reliability (Cronbach’s alpha 0.85) in DM patients [53]. Another study used the DES-SF [57] while one study used the DMSES [47], both of which have a good internal consistency of Cronbach alpha 0.85[58] and 0.91 [59], respectively. One study used the 6-item Stanford PERC Self-efficacy scale [45] while another study modified that scale to fit its local language and culture [56] with Cronbach’s alpha ranging from 0.83 to 0.95 [56, 60]. There is also a self-designed and validated self-efficacy tool [46].

A meta-analysis of six studies that reported self-efficacy scores of the intervention and control groups was conducted. It evaluated a total of 682 participants using a random effects model and SMD as its summary statistic due to the different psychometric scales used [32]. Studies pooled were statistically significant in improving self-efficacy, with a large effect size, favouring the smartphone-based interventions ($d = 0.98$; 95% confidence interval (CI) 0.42 to 1.55; $P < 0.001$). However, high and significant heterogeneity was found between the studies ($I^2 = 91%$; $P < 0.001$).
Subgroup analysis was conducted to compare the different modes of delivery (SMS: n = 4, smartphone applications: n = 3) and the duration of the interventions (less than 6 months: n = 4, 6 months to 1 year: n = 3). There were both significant differences between subgroups. SMS interventions showed statistically significant improvements in self-efficacy with large effect size, favouring the intervention (d = 1.46; 95% CI 0.42 to 2.50; P = .006). Pooling of studies that used smartphone application interventions showed statistically significant improvements in self-efficacy with small effect size, favouring the interventions (d = 0.39; 95% CI 0.16 to 0.61; P < 0.001). In additions, interventions that lasted less than six months showed a statistically significant large effect size, favouring the interventions (d = 1.52; 95% CI 0.56 to 2.48; P = .002). Interventions that lasted between six months to a year showed a statistically significant small effect, favouring the interventions (d = 0.34; 95% CI 0.13 to 0.54; P = .001).

Subgroup analysis was also conducted according to the mean HbA1c level of participants at baseline (HbA1c < 8%; n = 4, HbA1c > 8%; n = 3). A cut-off HbA1c level of 8% was chosen as the ADA recommended an HbA1c goal of < 8% for patients with more severe diabetes [31]. There were significant differences between subgroups (I^2 = 82.2%; P = .02). Studies that had participants with a mean baseline HbA1c < 8% showed a statistically significant large effect size, favouring the interventions (d = 1.52; 95% CI 0.56 to 2.48; P = .002). Studies that had participants with a mean baseline HbA1c > 8% showed a statistically significant small effect size, favouring the interventions (d = 0.34; 95% CI 0.13 to 0.54; P = .001).

Effectiveness of Interventions on Self-care Activities

Five out of six studies that reported self-care activities as an outcome used the SDSCA while one study used the SCI-R [47]. Both instruments have been demonstrated to have good internal consistency with Crobach’s alpha 0.73[56] and 0.87[61], respectively. Three studies (four arms) compared the overall post-intervention self-care activities scores between smartphone-based self-management intervention groups and control groups in the meta-analysis of 315 participants. Pooling of studies gave a statistically significant large effect size, favouring the interventions (d = 0.90; 95% CI 0.24 to 1.57; P < 0.001). However, high and significant heterogeneity was found between the studies (I^2 = 87%; P < 0.001). Three other studies also assessed for self-care activities post-intervention but did not report the overall scores and hence could not be pooled into the meta-analysis [36, 57, 52]. No subgroup analyses were performed as there were less than six studies in the pooled meta-analysis [62].
For the three studies, there was one study that used the SCI and reported significant improvements in overall self-care activities scores in both intervention arms from baseline and significant differences between both intervention arms and the control group at post-intervention [47]. It also reported a much greater mean difference in both of its intervention arms compared to the other studies in the pooled analysis which could have resulted in the substantial heterogeneity. Another study reported that when compared to the control group, its smartphone application intervention significantly improved participants’ overall self-care activities after three months [56]. The third study did not report any information on statistical significance in overall self-care scores between groups [45].

Effectiveness of Interventions on HRQoL

Only three studies measured for HRQoL of their participants, using the Diabetes-39 tool [53] with Cronbach’s alpha ranging from 0.82 to 0.93 [63], the PAID scale [57] with Cronbach’s alpha 0.95 [64], and the Thai DQOL scale with Cronbach’s alpha 0.89 [56].

The three studies compared the use of smartphone-based self-management interventions to control groups on the outcomes of the change in HRQoL scores in the meta-analysis of 371 participants (Figure 3). The effect of smartphone-based self-management interventions for the improvement of HRQoL was statistically significant with a small effect size ($d = 0.26; 95\% CI 0.06 to 0.47; P = .01$), favouring the interventions. There was no evidence of statistical heterogeneity between studies ($I^2 = 0\%; P = .92$). A fixed-effect model was used as heterogeneity was not significant [32].

![Figure 3](Image)

**Figure 3.** Forest plot: Effectiveness of smartphone-based self-management intervention on HRQoL
Effectiveness of Interventions on Clinical Outcomes

HbA1c

All 22 studies included in this review reported HbA1c levels. Only 18 studies (22 arms) were able to be pooled for meta-analysis. As seen in Figure 4, 18 studies were pooled with a total of 1980 participants. The effect of smartphone-based interventions on reduction in HbA1c was statistically significant (pooled MD = -0.55; 95% CI -0.60 to -0.40; \( P < 0.001 \)), favouring the interventions. Heterogeneity was statistically significant with low heterogeneity found between the studies (I^2 = 38%; \( P = .04 \)).

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Smartphone Mean</th>
<th>SD</th>
<th>Total</th>
<th>Control Mean</th>
<th>SD</th>
<th>Total</th>
<th>Weight</th>
<th>Mean Difference IV, Random, 95% CI</th>
<th>Mean Difference IV, Random, 95% CI</th>
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<tr>
<td>Abdoora 2016</td>
<td>-0.63</td>
<td>1.29</td>
<td>64</td>
<td>-0.21</td>
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<td>Aranda 2010</td>
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<td>89</td>
<td>9.56</td>
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<tr>
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<td>1.84</td>
<td>64</td>
<td>9.2</td>
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<td>84</td>
<td>4.4</td>
<td>0.20 (-0.75, 0.35)</td>
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</tr>
<tr>
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<td>58</td>
<td>7.04</td>
<td>1.24</td>
<td>51</td>
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<td>-0.49 (-0.93, -0.05)</td>
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</tr>
<tr>
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<td>1.21</td>
<td>50</td>
<td>8.4</td>
<td>2</td>
<td>58</td>
<td>3.8</td>
<td>-0.69 (-1.91, -0.32)</td>
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</tr>
<tr>
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<td>1.17</td>
<td>45</td>
<td>7.48</td>
<td>1.26</td>
<td>38</td>
<td>6.0</td>
<td>-0.45 (-0.86, 0.01)</td>
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</tr>
<tr>
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<td>108</td>
<td>-0.16</td>
<td>1.11</td>
<td>94</td>
<td>6.3</td>
<td>-0.67 (-0.97, -0.37)</td>
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</tr>
<tr>
<td>John 2007</td>
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<td>0.77</td>
<td>25</td>
<td>8.4</td>
<td>1.04</td>
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<td>5.0</td>
<td>-1.63 (-2.13, -1.13)</td>
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<tr>
<td>Klemman 2017</td>
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<td>45</td>
<td>8.2</td>
<td>1.6</td>
<td>45</td>
<td>4.5</td>
<td>-0.60 (-0.96, -0.15)</td>
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<tr>
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<td>24</td>
<td>0.038</td>
<td>0.86</td>
<td>24</td>
<td>6.6</td>
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<td>50</td>
<td>7.55</td>
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<tr>
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<tr>
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<td>21</td>
<td>8.5</td>
<td>1.6</td>
<td>17</td>
<td>1.6</td>
<td>-0.92 (-1.78, 0.04)</td>
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</tr>
<tr>
<td>Quin 2011b</td>
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<td>21</td>
<td>8.5</td>
<td>1.6</td>
<td>17</td>
<td>1.6</td>
<td>-0.92 (-1.64, 0.04)</td>
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</tr>
<tr>
<td>Quin 2011c</td>
<td>7.9</td>
<td>1.7</td>
<td>55</td>
<td>8.5</td>
<td>1.6</td>
<td>17</td>
<td>1.6</td>
<td>-0.92 (-1.66, 0.06)</td>
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</tr>
<tr>
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<td>0.88</td>
<td>52</td>
<td>7.34</td>
<td>0.86</td>
<td>52</td>
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<td>-0.36 (-1.66, -0.01)</td>
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<tr>
<td>Tolesjensen 2014a</td>
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<td>1.67</td>
<td>39</td>
<td>8.2</td>
<td>1.37</td>
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<td>3.2</td>
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<tr>
<td>Tolesjensen 2014b</td>
<td>8.13</td>
<td>1.49</td>
<td>40</td>
<td>8.2</td>
<td>1.37</td>
<td>21</td>
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<td>1.1</td>
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<td>Vongajaran 2015</td>
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<td>55</td>
<td>0.05</td>
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<td>You 2009</td>
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<td>57</td>
<td>7.8</td>
<td>1</td>
<td>54</td>
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<tr>
<td>Total (95% CI)</td>
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<td>902</td>
<td>100.0</td>
<td>-0.55 (-0.69, -0.40)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. Forest plot: Effectiveness of smartphone-based self-management intervention on HbA1c

As there were more than 10 studies in this meta-analysis, a funnel plot was used to examine for publication bias (Figure 5). The studies were not symmetrically distributed on both sides of the plot and a higher concentration is observed on one side of the mean line. This suggests that publication bias may be present [34].

Figure 5. Funnel plot for publication bias assessment
**BMI and Blood Pressure**

Nine studies (10 arms), with a total of 967 participants presented findings for BMI. The pooling of studies did not find smartphone-based self-management interventions to be statistically significant in improving BMI (pooled MD = -0.23; 95% CI -0.76 to 0.29; \( P = .39 \)). No significant heterogeneity was found between studies (\( I^2 = 7\%; \ P = .38 \)).

Nine studies (11 arms), with a total of 904 participants presented findings for systolic blood pressure (SBP) and diastolic blood pressure (DBP). The pooling of studies did not find smartphone-based self-management interventions to be statistically significant in improving SBP (pooled MD = -1.17; 95% CI -3.17 to 0.83; \( P = .25 \)). No significant heterogeneity was found between studies (\( I^2 = 0\%; \ P = 0.73 \)). The interventions were not statistically significant in improving DBP either (pooled MD = -0.49; 95% CI -1.67 to 0.68; \( P = .41 \)). No significant heterogeneity was found between studies (\( I^2 = 0\%; \ P = .47 \)).

**Summary of Findings**

Our meta-analysis showed that smartphone-based self-management interventions were statistically significant in improving self-efficacy and self-care activities. However, high heterogeneity was detected among studies pooled for both outcomes and subgroup analyses for self-efficacy were conducted for mode of delivery, duration of intervention and baseline HbA1c. In addition, the interventions were statistically significant in improving HRQoL and HbA1. However, the effects on BMI and BP were not statistically significant.

**Discussion**

To the best of our knowledge, this is the first meta-analysis to quantify the magnitude improvement on self-efficacy, self-activity, HRQoL, and HbA1c from smartphone-based self-management interventions. A possible reason for the large effect size on self-efficacy in this review can be due to self-management intervention components present in the smartphone-based interventions as evidenced in a review on self-management interventions for T2DM [65]. This is also supported by the theory of self-efficacy as the smartphone-based self-management interventions can increase participants’ confidence in regularly carrying out self-care activities through daily reminders, education, self-monitoring tasks and personalized feedback [19]. Through these components, mechanisms of performance accomplishments, vicarious experience, verbal persuasion and emotional arousal are being applied, thus positively influencing self-efficacy [66].
SMS interventions yielded greater improvements in self-efficacy. A possible reason is the simplicity and familiarity of text messages compared to newly-introduced smartphone applications [28]. Information relayed via SMS can provide assurance to individuals on their own capability for coping with T2DM and reduce uncertainties as any educational materials, reminders or feedback previously given are easily accessible, thus increasing their sense of self-efficacy [28, 66]. Smartphone applications are more prone to technical issues such as software glitches and restricted access due to the need for a stable wireless connection which can be major barriers to effective remote health interventions [67]. However, more research needs to be conducted to confirm these findings. Moreover, it was also observed that studies with intervention duration of less than six months produced a large effect size whereas studies with intervention duration of more than six months produced a small effect size. Intervention durations of less than six months has been supported by reviews evaluating the effectiveness of smartphone-based interventions on glycaemic control where reductions in HbA1c were larger in interventions that lasted less than 6 months [18, 27, 28]. This could be due to the fact that shorter durations of intervention increase the likelihood of remembering and applying what was learnt, thus increasing confidence and motivation in managing their condition [28]. In addition, participants with HbA1c levels of less than 8% at baseline showed large improvements in self-efficacy whereas those with HbA1c levels more than 8% showed small improvements in self-efficacy. This implies that patients with better glycaemic control at baseline benefitted more from the smartphone applications [25, 31]. A possible reason for the difference in self-efficacy improvements in this review could be that individuals with HbA1c levels > 8% are more likely to already have diabetic complications which can affect their ability to adhere to self-care activities [31]. Applying the self-efficacy theory, these individuals may be less motivated and possible past failures in adhering to self-care activities can lower personal mastery expectations of their ability in carrying out those activities [66, 68]. Thus, it is harder for these individuals to have large improvements in their self-efficacy compared with their counterparts with baseline HbA1c < 8% [69].

In this review, self-care activities showed a large improvement with smartphone-based self-management interventions. This is attributed to behavioural change techniques utilised in the web-based interventions where providing feedback on performance, education on consequences of behaviour and prompting self-monitoring behaviour are the main techniques associated with improvement of health behaviours [19]. Since similar techniques are also found in the smartphone-based self-management interventions included in this review, it may
be the reason why self-care activities are improved despite the difference in the mode of technology used. In a previous review [70], internet-based interventions did not show significant improvements in diet and physical activity. A possible reason for the lack of improvement may be attributed to the inconsistency in the levels of engagement with the web-based programs. Thus, maintaining patient engagement is an important determinant in the effectiveness of interventions in promoting self-care activities. Smartphone-based interventions have the advantage of being easy-to-use and widely accessible and thus, can keep patients engaged longer, increasing their effectiveness on self-care activities [71]. Furthermore, the improvement in self-care activities reported can also be associated with an increase in self-efficacy, both reported in this review. Self-efficacy enables people to trust themselves and to use their skills to overcome any challenges faced, leading to successful adherence to self-care activities in T2DM [69, 72]. High heterogeneity was also found, which was expected as previous systematic reviews evaluating telehealth or mobile health intervention effects [17, 23]. In this review, the high heterogeneity could be due to the use of a variety of measurement tools, differences in intervention components and self-care domains covered.

The self-management components could have been the contributing factor to the significant improvement, albeit small, in HRQoL. The small effect size in this meta-analysis is comparable to the small effect size observed in self-management interventions on patients with diabetes for HRQoL [73]. There is a strong relationship between self-efficacy and HRQoL [74]. This could be attributed to how with enhanced self-efficacy, individuals are more confident of their mastery in certain tasks and also in managing difficult situations [66]. Having self-efficacy also reduces fear and distress in diabetes management which is commonly measured in diabetes-related quality of life tools, resulting in the improvement seen in HRQoL scores [66, 75]. Nevertheless, due to the small sample size in this meta-analysis, more studies are needed to confirm the effectiveness of smartphone-based self-management interventions on HRQoL. Smartphone-based self-management interventions were also found to reduce HbA1c levels for patients with T2DM. This can be attributed to the self-care domains that were targeted in the interventions such as medication adherence, diet, physical activity and SMBG which has been found to improve glycaemic control and HbA1c levels [76]. Furthermore, greater self-efficacy is also associated with lower HbA1c levels as self-efficacy improves patients’ understanding of their condition and increases their motivation to manage their diabetes better [77]. Meta-analysis in this review reported that
smartphone-based self-management interventions had a non-significant reduction of BMI and BP. This is supported by previous meta-analyses where BMI was also not significantly improved following computer-based or text-message interventions [23, 78], and there were no significant effects of smartphone applications on SBP and DBP when compared to usual care [25]. These findings might indicate that BP and BMI are not related to self-efficacy and self-care activities. However, more research is needed to clarify this relationship in the future.

Limitations

There were some limitations in this review. Firstly, only English language articles were included, which may introduce language bias, as non-English articles with relevant outcomes were missed. Secondly, study intervention descriptions were often brief and deciding which interventions fitted our definition often required discussion between the three reviewers and judgements were based on limited descriptions and interpretation. Thirdly, it would be the high risk of bias present in most studies. Most studies were unable to blind the participants and outcome assessors and reported incomplete outcome data. The low quality of the eligible studies could have affected the results of the meta-analyses [32]. Lastly, this meta-analysis was the high heterogeneity found for the outcomes including self-efficacy and self-activity.

Conclusions

In conclusions, the findings from the current review provide evidence that self-efficacy and self-care activities showed a large effect size, favouring smartphone-based self-management interventions. High heterogeneity was found and explored with subgroup analyses for self-efficacy. A possible reason for heterogeneity is the wide variety of self-report tools used and the variation in intervention characteristics between studies. Narrative syntheses were also done for outcomes with high heterogeneity and studies that could not be pooled into meta-analyses. Other meta-analyses revealed a small improvement in HRQoL, a moderate reduction in HbA1c and non-significant improvements in BMI and BP.

Acknowledgments

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Conflict of interest

None declared.
Multimedia Appendix 1
Search strategy.

Multimedia Appendix 2
Summary of included studies.

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Abbreviations

AADE: American Association of Diabetes Educators
ADA: American Diabetes Association
BGM: Blood Glucose Monitoring
BMI: Body Mass Index
BP: Blood Pressure
CI: Confidence Interval
CINAHL: Cumulative Index to Nursing and Allied Health Literature
DBP: Diastolic Blood Pressure
GRADE: Grading of Recommendations, Assessment, Development and Evaluation
HbA1c: Glycated Haemoglobin
HRQoL: Health-related Quality of Life
ITT: Intention-to-Treat
MD: Mean Difference
MeSH: Medical Subject Heading
PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RCT: Randomised Controlled Trial
SBP: Systolic Blood Pressure
SD: Standard Deviation
SMD: Standardised Mean Difference
SMS: Short Message Service
T2DM: Type 2 Diabetes Mellitus
WHO: World Health Organisation