# Computer-Based Interventions to Improve Self-management in Adults With Type 2 Diabetes: A Systematic Review and Meta-analysis

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**OBJECTIVE**

**Structured patient education programs can reduce the risk of diabetes-related complications. However, people appear to have difficulties attending face-to-face education and alternatives are needed. This review looked at the impact of computer-based diabetes self-management interventions on health status, cardiovascular risk factors, and quality of life of adults with type 2 diabetes.**

**RESEARCH DESIGN AND METHODS**

**We searched The Cochrane Library, Medline, Embase, PsycINFO, Web of Science, and CINAHL for relevant trials from inception to November 2011. Reference lists from relevant published studies were screened and authors contacted for further information when required. Two authors independently extracted relevant data using standard data extraction templates.**

**RESULTS**

**Sixteen randomized controlled trials with 3,578 participants met the inclusion criteria. Interventions were delivered via clinics, the Internet, and mobile phones. Computer-based diabetes self-management interventions appear to have small benefits on glycemic control: the pooled effect on $HbA_{1c}$ was −0.2% (−2.3 mmol/mol [95% CI −0.4 to −0.1%]). A subgroup analysis on mobile phone–based interventions showed a larger effect: the pooled effect on $HbA_{1c}$ from three studies was −0.50% (−5.46 mmol/mol [95% CI −0.7 to −0.3%]). There was no evidence of improvement in depression, quality of life, blood pressure, serum lipids, or weight. There was no evidence of significant adverse effects.**

**CONCLUSIONS**

**Computer-based diabetes self-management interventions to manage type 2 diabetes appear to have a small beneficial effect on blood glucose control, and this effect was larger in the mobile phone subgroup. There was no evidence of benefit for other biological, cognitive, behavioral, or emotional outcomes.**

The burden of diabetes is growing, with 347 million people currently affected worldwide (1) and numbers projected to increase to 552 million by 2030 (2). The International Diabetes Federation suggests that in the developed world, the cost of caring for patients with diabetes is double that of the background population, and

META-ANALYSIS

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the estimated cost of managing people diagnosed with diabetes in the U.S. in 2007 was $174 billion (3). Improving self-management is an important component of improving cost-effective patient-centered care and dealing with this growing health care challenge (4,5).

The current gold standard for self-management is face-to-face group education (6,7). However, current attendance of diabetes education is poor (8). Digital interventions have the potential to increase access to self-management training and improve outcomes if this can be done effectively. This review summarizes the effects of computer-based self-management interventions on adults with type 2 diabetes and uses a taxonomy of behavior-change techniques to describe the potential active components of these complex interventions. Included interventions were defined as any application that took input from a patient and used communication or processing technology to provide a tailored response, facilitating one or more aspect of diabetes self-management. Interventions used mainly for communication between patients and professionals were not included in the review.

## RESEARCH DESIGN AND METHODS

We searched the following electronic databases for trials or conference proceedings from inception until November 2011: The Cochrane Library, Medline, Embase, PsycINFO, Web of Science, and CINAHL. The search strategy for Medline can be found in Supplementary Table 1. Three other databases were searched for gray literature: Aslib Index to Theses, Australasian Digital Theses Program, and ProQuest Digital Dissertations and Theses. Reference lists from relevant published studies were screened and authors contacted for further information when required.

Included studies were randomized, controlled clinical trials involving patients aged ≥18 years with type 2 diabetes mellitus. Interventions met the following criteria for inclusion: interact with users to generate tailored content that aimed to improve one or more diabetes self-management domains through feedback, advice, reinforcement, and rewards, patient decision support, goal setting, or reminders. Studies published in any language were included. We excluded studies of interventions that were targeted only at patients with type 1 diabetes, involved participants aged <18 years, used only for communication between patients and professionals, or targeted at health professionals. Studies of mixed populations of patients in which there was a majority of patients with type 2 diabetes were included, but where possible, only data for patients with type 2 diabetes were included in analyses. Possible comparison groups included standard diabetes care, noninteractive computer-based programs, paper educational material, delayed start/waiting list, or face-to-face self-management education. Primary outcomes were health-related quality of life, $HbA_{1c}$, or death from any cause. Secondary outcomes were changes in cognitions, behaviors, social support, cardiovascular risk factors (blood pressure, serum lipids, and weight), complication rates, emotional outcomes, hypoglycemia, adverse effects, cost-effectiveness, and economic data.

Two authors independently scanned the abstracts of retrieved reports and potentially relevant articles were investigated as full text. For studies that fulfilled the inclusion criteria, two authors independently extracted data using standard data extraction templates with any disagreements resolved by discussion with the study steering group. Any relevant missing information on the trial was sought from the original author(s) of the article. Quality assessment of the included studies used the Cochrane Collaboration's tool (9) for risk of bias assessment.

Statistical analysis was performed according to the guidelines referenced in version 5.1.0 of the *Cochrane Handbook for Systematic Reviews of Interventions* (9). Where studies provided sufficient data for meta-analysis, the Cochrane Collaboration's RevMan software was used to perform a meta-analysis pooling the mean difference or difference in means. Where outcomes were measured on different scales, standardized mean differences were combined. In studies in which outcome data were not suitable for meta-analysis, the data were described narratively. Meta-analyses were based on a random-effects model. Heterogeneity was identified by visual inspection of the forest plots and examined with the $I^2$ statistic to quantify inconsistency across studies (9).

### Specifying the Content of the Intervention and Control Conditions

The intervention and control conditions were coded in terms of their component active ingredients using a taxonomy of behavior-change techniques (10) (Supplementary Table 2). The two authors recorded if reports of a theoretical mechanism were mentioned and whether it was applied to the intervention. There were too few studies to conduct a meta-regression to investigate which behavior-change techniques were effective in the interventions, so an exploratory exercise was conducted involving comparison of the techniques that featured most commonly in effective interventions to those featuring most commonly in ineffective interventions. Prespecified subgroup analyses were performed on duration of intervention and setting.

## RESULTS

### Descriptions of Studies

Database searches yielded 8,715 unique abstracts, of which 94 full-text articles were assessed for eligibility. Twenty journal articles describing 16 different studies with 3,578 participants fulfilled the inclusion criteria and were selected for inclusion in the review (Fig. 1). A summary of study characteristics can be found in Table 1.

The numbers of participants ranged from 30 (11,12) to 886 (13) in each study. One only included women (12). Participants in one study (14) were all Latin or Hispanic. Three studies (13,15,16) reported that >70% of participants were Caucasian or non-Hispanic white. In 13 studies, all participants had type 2 diabetes; 3 studies (12,17,18) included participants with both type 1 and type 2 diabetes; the percentage of participants with type 1 diabetes ranged from 19–26%. Six studies (11,17,19–22) reported mean duration of diabetes with a range of between 6 and 13 years. The mean age of participants ranged from 46 (12) to 67 (19) years. Supplementary Table 3 summarizes the interventions and controls used in the included studies.

Only three interventions referenced psychological theories (15,20,23). These included the transtheoretical model, social ecological theory, social cognitive theory, and self-determination theory.

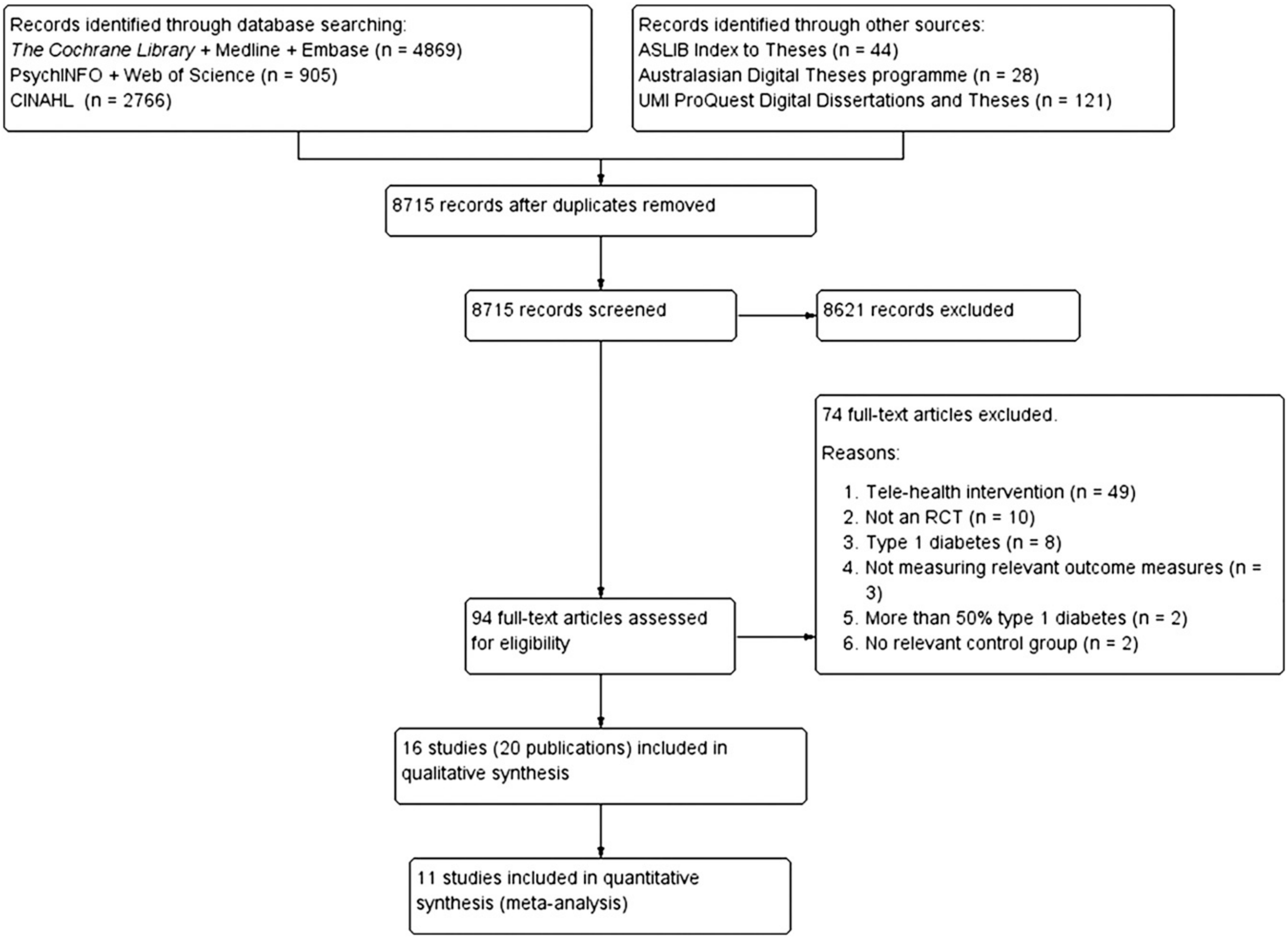


**Figure 1**—Preferred reporting items for systematic reviews and meta-analyses flowchart. RCT, randomized controlled trial.

The behavior-change techniques used in each intervention are described in Supplementary Table 4. A summary of the outcome data from all the studies is provided in Supplementary Table 5.

### Overall Study Quality

Details of the risk of bias assessment of the included studies can be found in Supplementary Table 6. All of the included studies were randomized controlled trials but none were blinded, with most reports citing study design challenges as the main reason for this.

Two studies appeared to be at high risk of selection bias. One study used an inadequate randomization procedure (21), and another had a high attrition rate of 39% in the intervention group (20). A summary of the strength of the evidence can be found in Supplementary Table 7.

### Study Outcomes

Most studies measured a number of outcome measures to reflect clinical and service-user priorities. These included biological markers, cognitive outcomes, behavioral outcomes, emotional outcomes, cost-effectiveness, and adverse event data.

#### *Cardiovascular Risk Factors*

All of the studies had $HbA_{1c}$ as an outcome measure and 11 studies (13–16,18–20,22–25) provided enough data to combine in a meta-analysis, as shown in Fig. 2. Pooled results indicate that there is a small, statistically significant difference in the outcomes between intervention and comparator groups of 2.3 mmol/mol or −0.21% (95% CI −0.37 to −0.05%), favoring the intervention group. However, there was substantial heterogeneity in the effects interventions ($I^2$ = 58%). Possible reasons for the heterogeneity were explored in a sensitivity analysis, described below.

Five studies (14,18,20,22,23) looked at changes in blood pressure, and one study showed evidence of improvement.

Seven studies (14,15,17,19,22,23,25) reported changes in BMI or weight, and five studies (14,15,19,22,23) were combined in a meta-analysis. The overall pooled effect did not reach statistical significance (pooled standardized mean difference −0.07 [95% CI −0.20 to 0.05]) (Supplementary Fig. 3).

Ten studies (13–15,17,19,20,22–25) measured serum lipids, and seven (13–15,19,20,22,23) were combined in a meta-analysis. The overall pooled effect did not reach statistical significance (pooled standardized mean difference −0.11 [95% CI, −0.28 to 0.05]) (Supplementary Fig. 4). One study (14) attributed the difference in lipids to differences in the use of lipid-lowering medication between the two study groups.

#### *Cognitive Outcomes*

All four studies (11,16,21,26) that looked at change in knowledge and understanding reported positive effects of the interventions on knowledge. Two

**Table 1—Summary of study characteristics**

| Study (reference number) | Setting | Sex (% female) | Age [mean years (SD)] | $HbA_{1c}$ [mean % (SD)] | BMI [mean kg/m$^2$ (SD)] | Duration of disease [mean years (SD)] | Ethnic groups (%) | Country | Duration of intervention |
|---|---|---|---|---|---|---|---|---|---|
| Christian 2008 (14) | Clinic-based | I: 65<br>C: 68 | I: 53.0 (11.3)<br>C: 53.4 (10.7) | I: 8.1 (2)<br>C: 8.3 (1.9) | I: 35.4 (6.6)<br>C: 34.8 (7.1) | —<br>— | >60% Latin/Hispanic | U.S. | One 30-min exposure |
| Glasgow 1997 (17) | Clinic-based | I: 63<br>C: 60 | I: 61.7 (12.1)<br>C: 63.1 (10.5) | I: 7.9<br>C: 7.9 | I: 30.4<br>C: 30.2 | I: 13.0 (9.9)<br>C: 13.7 (12.2) | —<br>— | U.S. | 3× 30 min |
| Glasgow 2003 (24) | Internet-based | —<br>— | —<br>— | I: 7.5 (1.7)<br>C: 7.4 (1.6) | —<br>— | —<br>— | —<br>— | U.S. | 10 months |
| Glasgow 2005 (13) | Clinic-based | I: 52<br>C: 50 | I: 62 (1.4) SE<br>C: 64 (1.3) SE | I: 7.3 (1.3)<br>C: 7.3 (1.2) | —<br>— | —<br>— | I: white, 83.5%; black, 1.7%; Hispanic, 11.3%; other, 3.4%<br>C: white, 77.9%; black, 2.7%; Hispanic, 14.1%; other, 5.4% | U.S. | 12 months |
| Glasgow 2006 (15) | Clinic-based | I: 50<br>C: 50 | I: 62.0 (11.7)<br>C: 61.0 (11.0) | I: 7.4 (1.6)<br>C: 7.5 (1.6) | —<br>— | I: at least 6 months<br>C: at least 6 months | I: white, 74.1%; Hispanic, 17.5%<br>C: white 79.6%; Hispanic, 18.3% | U.S.<br>U.S. | One exposure to intervention<br>2 phone calls |
| Glasgow 2010 (23) | Internet-based | I: 45<br>C: 52 | I: 58.7 (9.3)<br>C: 58.7 (9.1) | I: 8.0 (1.9)<br>C: 8.1 (1.8) | I: 34.5 (6.3)<br>C: 34.8 (6.6) | —<br>— | I: American Indian/Alaska Native, 4.9%; Asian, 1.9%; black or African American, 14.8%; white, 74.1%; Latino ethnicity, 25.3%<br>C: American Indian/Alaska Native, 11.1%; Asian, 1.6%; black or African American, 12.7%; white, 70.6%; Latino ethnicity, 16.8% | U.S. | 4 months |
| Leu 2005 (18) | Pagers | —<br>— | Average age of 51 years | I: 8.5<br>C: 8.5 | —<br>— | —<br>— | Predominantly Caucasian | U.S. | 3–6 months |
| Lim 2011 (19) | Mobile phones | I: 54 | I: 67.2 (4.1) | I: 7.8 (1.0) | I: 24.7 (2.4) | — | — | South Korea | 6 months |
| Lo 1996 (26) | Clinic-based | I: 75<br>C: 50 | I: 61.6 (11.6)<br>C: 63.4 (8.9) | Nonstandard units | —<br>— | —<br>— | —<br>— | Australia | I: 3–6 sessions, 1 h each<br>C: 4 weekly sessions 2.5–3 h |
| Lorig 2010 (16) | Internet-based | I: 64<br>C: 71 | I: 54.2 (9.9)<br>C: 54.4 (10.6) | —<br>— | —<br>— | —<br>— | I: 78% non-Hispanic white<br>C: 71.1% non-Hispanic white | U.S. | 6–18 months |
| Quinn 2008 (11) | Mobile phones | I: 69<br>C: 62 | I: 8 aged 20–54, 5 aged 55–64 years<br>C: 6 aged 20–54, 7 aged 55–64 years | I: 9.5<br>C: 9.1 | —<br>— | I: 7.6<br>C: 11 | I: 10 of 13 African, 77%; 3 of 13 non-Hispanic white, 23%<br>C: 6 of 13 African, 46%; 7 of 13 non-Hispanic white, 54% | U.S. | 3 months |

*Continued on p. 1763*

**Table 1—Continued**

| Study (reference number) | Setting | Sex (% female) | Age [mean years (SD)] | $HbA_{1c}$ [mean % (SD)] | BMI [mean $kg/m^2$ (SD)] | Duration of disease [mean years (SD)] | Ethnic groups (%) | Country | Duration of intervention |
|---|---|---|---|---|---|---|---|---|---|
| Quinn 2011 (20) | Mobile phones | I: 48<br>C: 50 | I: 52.8 (8.0)<br>C: 53.2 (8.4) | I: 9.3 (1.8)<br>C: 9.2 (1.7) | I: 36.9 (7.5)<br>C: 34.3 (6.3) | I: 7.7 (5.6)<br>C: 9.0 (7.0) | I: black (non-Hispanic) 43.5%; white (non-Hispanic) 52.2%; other 4.3%<br>C: black (non-Hispanic) 48.2%; white (non-Hispanic) 46.4%; other 5.4% | U.S. | 12 months |
| Smith 2000 (12) | Internet-based | All: 100 | Mean age 46.7 years | —<br>— | —<br>— | —<br>— | —<br>— | U.S. | 5 months |
| Wise 1986 (21) | Clinic-based | —<br>— | 55 (21) SE | I: 8.7 (0.7)<br>C: 8.7 | —<br>— | I: 8 (5) SE<br>C: 7 (4) SE | —<br>— | U.K. | 4–6 months |
| Yoo 2009 (22) | Mobile phones | I: 47<br>C: 35 | I: 57.0 (9.1)<br>C: 59.4 (8.4) | I: 7.6 (0.9)<br>C: 7.4 (0.9) | I: 25.6 (3.5)<br>C: 25.5 (3.3) | I: 6.0 (5.4)<br>C: 7.2 (6.0) | —<br>— | South Korea | 12 weeks |
| Zhou 2003 (25) | Internet-based | I: 61<br>C: 56 | I: 62.4 (8.3)<br>C: 59.8 (11.0) | I: 8.7 (1.5)<br>C: 9.0 (1.8) | I: 24.0 (3.1)<br>C: 24.5 (2.8) | —<br>— | —<br>— | China | 8 weeks |

C, control; I, intervention.

studies (11,16) reported on changes in self-efficacy, and both studies showed positive effects of the interventions.

#### *Behavioral Outcomes*

The effects of interventions on physical activity were mixed. One study (14) showed a statistically significant increase in the number of patients achieving ≥150 metabolic equivalent of task min of physical activity a week, and another (23) showed a statistically significant improvement in physical activity based on a subgroup analysis. Three studies (11,16,24) found no improvement in physical activity scores. The six studies (11,13,14,15,23,24) that looked at changes in diet reported statistically significant improvements in intervention groups.

#### *Effect on Emotional Outcomes*

None of the studies (11,13,15,16,20,24) that looked at depression showed evidence of improvements in the intervention groups.

#### *Cost-effectiveness Data*

Two studies provided data on cost-effectiveness. Glasgow et al. (17) looked at the cost per patient for a touch-screen dietary intervention. Depending on the volume of patients seen, the cost per patient in 1997 ranged from $115–139, with a cost per unit reduction of cholesterol between $7 and $8.40 and a cost per 1% reduction in fat of $52 and $63. One study (16) investigated health behavior and resource utilization but found no difference between intervention or control groups.

#### *Adverse Events*

One study (21) reported a participant withdrawing due to anxiety. A total of three participants died during the studies, but no deaths were attributed to the interventions. There were no reported statistically significant differences in hypoglycemic episodes between groups in any of the studies.

#### *Subgroup Analyses*

A previous meta-analysis of diabetes self-management interventions (18 of 20 were face to face) showed a greater effect from shorter studies with short-term follow-up (27). Therefore, we did a subgroup analysis to see if this hypothesis might also be true for computer-based self-management interventions. The studies were divided into those with follow up of <6 months and those with follow-up for ≥6 months. When outcomes at <6 months were combined

| Study or Subgroup | Computer intervention Mean [%] | SD [%] | Total | Control Mean [%] | SD [%] | Total | Weight | Mean Difference IV, Random, 95% CI [%] |
|---|---|---|---|---|---|---|---|---|
| **1.1.1 Change in mean** | | | | | | | | |
| Christian 2008 | -0.141 | 1.76 | 141 | -0.46 | 1.63 | 132 | 8.4% | 0.32 [-0.08, 0.72] |
| Leu 2005 | -0.13 | 0.93 | 18 | -0.3 | 1.12 | 19 | 4.4% | 0.17 [-0.49, 0.83] |
| Lorig 2010 | -0.009 | 0.852 | 395 | 0.126 | 0.779 | 238 | 16.3% | -0.14 [-0.26, -0.01] |
| **Subtotal (95% CI)** | | | **554** | | | **389** | **29.1%** | **0.06 [-0.27, 0.39]** |
| Heterogeneity: Tau² = 0.05; Chi² = 5.02, df = 2 (P = 0.08); I² = 60% | | | | | | | | |
| Test for overall effect: Z = 0.34 (P = 0.73) | | | | | | | | |
| **1.1.2 Mean difference** | | | | | | | | |
| Glasgow 2003 | 7.42 | 1.1 | 80 | 7.68 | 1.1 | 80 | 9.9% | -0.26 [-0.60, 0.08] |
| Glasgow 2005 | 7.14 | 1.38 | 290 | 7.13 | 1.06 | 270 | 14.1% | 0.01 [-0.19, 0.21] |
| Glasgow 2006 | 7.3 | 1.5 | 147 | 7.5 | 1.8 | 152 | 9.0% | -0.20 [-0.58, 0.18] |
| Glasgow 2010 | 7.84 | 1.67 | 130 | 8 | 1.58 | 115 | 8.3% | -0.16 [-0.57, 0.25] |
| Lim 2011 | 7.4 | 1 | 49 | 7.8 | 1 | 48 | 8.5% | -0.40 [-0.80, -0.00] |
| Quinn 2011 | 7.7 | 1 | 21 | 8.5 | 1.8 | 51 | 4.4% | -0.80 [-1.45, -0.15] |
| Yoo 2009 | 7.1 | 0.8 | 57 | 7.6 | 1 | 54 | 10.0% | -0.50 [-0.84, -0.16] |
| Zhou 2003 | 8.03 | 1.09 | 88 | 8.77 | 1.74 | 62 | 6.7% | -0.74 [-1.23, -0.25] |
| **Subtotal (95% CI)** | | | **862** | | | **832** | **70.9%** | **-0.32 [-0.52, -0.12]** |
| Heterogeneity: Tau² = 0.04; Chi² = 15.76, df = 7 (P = 0.03); I² = 56% | | | | | | | | |
| Test for overall effect: Z = 3.20 (P = 0.001) | | | | | | | | |
| **Total (95% CI)** | | | **1416** | | | **1221** | **100.0%** | **-0.21 [-0.37, -0.05]** |
| Heterogeneity: Tau² = 0.04; Chi² = 23.98, df = 10 (P = 0.008); I² = 58% | | | | | | | | |
| Test for overall effect: Z = 2.63 (P = 0.009) | | | | | | | | |
| Test for subgroup differences: Chi² = 3.70, df = 1 (P = 0.05), I² = 73.0% | | | | | | | | |

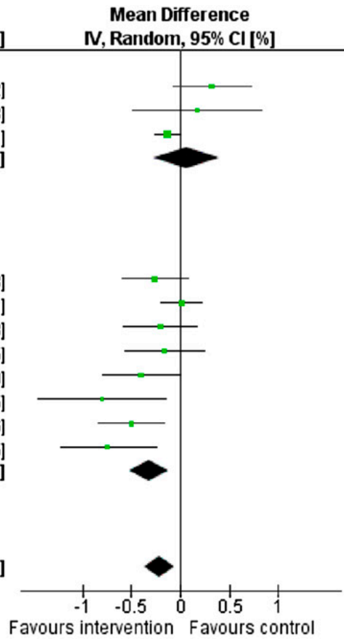


**Figure 2**—Forest plot of meta-analysis of $HbA_{1c}$ results.

(15,18,22,23,25), heterogeneity was reduced ($I^2$ = 43%) with a larger effect size for $HbA_{1c}$ of −3.5 mmol/mol or −0.3% (95% CI −0.6 to −0.1). Combining studies with outcomes measured at ≥6 months (13,14,16,19,20,24), the overall effect size for $HbA_{1c}$ was smaller and no longer statistically significant: −1.5 mmol/mol or −0.1% (95% CI −0.3 to 0.1), with substantial heterogeneity ($I^2$ = 61%).

Pooling the results of the three mobile phone–based interventions (19,20,22) identified a statistically and clinically significant reduction in $HbA_{1c}$ of −5.5 mmol/mol or −0.5% (95% CI −0.7 to −0.3) with no heterogeneity ($I^2$ = 0%). Interventions delivered at home (16,23–25) appeared to have a smaller effect: −2.7 mmol/mol or −0.3% (95% CI −0.5 to −0.04%), and the result was still associated with moderate heterogeneity ($I^2$ = 47%).

As the interventions showed significant heterogeneity in the overall pooled result ($I^2$ = 58%), a sensitivity analysis was done to explore possible reasons. An analysis was performed excluding three studies for methodological reasons: one study (14) noted that participants in the control group had larger changes in hypoglycemic medication than the intervention group, and two other studies (13,20) were cluster randomized but analyzed as individually randomized trials. Removing these studies increased the pooled effect slightly to 2.95 mmol/mol or −0.27% (95% CI −0.42 to −0.12%).

### *Behavior-Change Techniques Used by Interventions*

The two behavior-change techniques used most commonly by effective interventions were: prompt self-monitoring of behavioral outcome and provide feedback on performance. In contrast, the three techniques most commonly associated with interventions that had no significant impact on $HbA_{1c}$ were provision of information on consequences of behavior in general, goal setting (behavior), and barrier identification/problem solving.

## CONCLUSIONS

Computer-based diabetes self-management interventions appear to have small benefits on glycemic control (pooled effect on $HbA_{1c}$: −2.3 mmol/mol or −0.2%; 95% CI −0.4 to −0.1%; $I^2$ = 58%). A subgroup analysis on mobile phone–based interventions showed a larger effect (pooled effect on $HbA_{1c}$ from three studies: −5.46 mmol/mol or −0.50%; 95% CI −0.7 to −0.3%; $I^2$ = 0%). Current interventions do not appear to be effective in improving depression, quality of life, or weight. There was no evidence of significant adverse effects.

Evidence on the use of new technology in diabetes is still evolving, with mixed results. However, there are trends emerging that may highlight the aspects of self-management that might be effectively supported through computer-based interventions and the areas that may require more intensive or face-to-face input. The results of this review are supported by findings from a previous qualitative review that looked at 26 studies of interactive computer-assisted technology in diabetes care (28). It identified 14 studies that looked at $HbA_{1c}$ levels and found that 6 of 14 demonstrated significant declines in $HbA_{1c}$. Studies that looked at changes in body weight, blood pressure, microalbuminuria, and renal function found no significant differences postintervention, while effects on lipids and depression were mixed.

### The Impact of Mobile Phone Interventions

A recent review focused on the effect of mobile phone interventions for diabetes on glycemic control (29) and carried out a meta-analysis of 22 trials with 1,657 participants. This showed that mobile phone interventions for diabetes self-management reduced $HbA_{1c}$ values by a mean of 6 mmol/mol or 0.5% (95% CI 0.3 to 0.7) over a median follow-up duration of 6 months. This is similar to the effect size seen in this review when the effects of the three mobile phone interventions (19,20,22) were pooled.

The benefit identified with mobile phone interventions may be related to feedback on performance and prompts for blood glucose self-monitoring. This would be consistent with Control Theory. Previous reviews of interventions to increase physical activity and healthy eating (10,30,31) identified a cluster of techniques consistent with Control Theory (32) that were associated with effective interventions. These included receiving information about one's behavior (via self-monitoring or feedback) and having a strategy for acting on this information (action planning or information on where and when to perform the behavior). This also appears to be true for interventions aimed at health professionals. A recent review found that computer decision support systems aimed at primary care clinicians were only likely to improve patient outcomes if they provided feedback on performance, reminders, and case management (33). It is potentially significant that similar techniques are effective in interventions targeted at different audiences. Providing feedback and prompting behavior appear to be critical elements of behavior change for both professionals and patients, and maximizing improvements in patient outcomes may require complementary interventions designed to change behavior in both clinicians and patients: a meta-regression of computerized clinical decision support systems found that provision of advice to both practitioners and patients improved the success of such systems (34).

### Limitations of the Review

There are a number of limitations that could affect the results of the review. Although all of the included studies were randomized control trials, they were not double blinded, which may have affected the treatment from health care professionals involved in the study and/or the study investigators. Some of the control groups had potentially active interventions that might reduce the apparent effectiveness of the interventions (e.g., increases in hypoglycemic medication, goal setting, or increased monitoring by health care providers). Finally, the literature search was run from inception until November 2011, and studies published after that date are not included. To estimate the impact of the age of the search, the Medline search was rerun from November 2011 to January 2014, and 963 more abstracts were screened. This search identified two relevant publications, of which one was a follow-up from a study that has been included in the meta-analysis. There were 16 protocols published for studies that are currently in progress. The results are therefore likely to reflect the current evidence base at the time of publication, but this picture is likely to evolve over the next few years.

### Implications for Future Research

There were few published protocols for the studies, and the theoretical bases of the interventions were not always clearly described in the published reports. As these interventions are therapeutic agents, it would be beneficial to explicitly prescribe interventions for trials and formally state the active ingredients (behavior-change techniques), dose (frequency and intensity of interactions), route (mode of delivery, Internet, mobile phone, etc.), and duration of treatment.

It is also not clear why interventions delivered over mobile phones appear to be more effective; it could be due to convenience (and therefore adherence), intensity of the interventions (mobile phone interventions were more likely to have multiple daily contacts), or the behavior-change techniques used by the interventions (mobile phone interventions were more likely to use cues to prompt behavior and provide rapid feedback afterward).

A clear understanding of the mechanism of action of effective interventions may also facilitate systemic improvements through complementary interventions that cover the whole system of health care delivery. Health care professionals and patients both appear to benefit from computerized prompts and feedback, and the optimal solution to maximize improved outcomes may be systems that are able to target both populations.

The small treatment effect (2.3 mmol/mol or 0.2%) on $HbA_{1c}$ with computer-based self-management interventions would be important if it could be achieved and sustained across the population via the Internet (at very low cost), but far from cost-effective if it required significant health professional support and/or additional drugs. More studies with longer follow-up are needed to determine the cost-effectiveness of different types of computer-based interventions, the long-term impact on health outcomes, and to look for evidence of harm.

There also needs to be more research done to determine which population groups will benefit the most from these interventions (e.g., $HbA_{1c}$ >53 mmol/mol or 7%) and the impact of these interventions on older patients. There are also questions surrounding the "digital divide" and whether access to such interventions or their effectiveness might be influenced by age, education, computer literacy, culture, and affluence.

### Conclusion

Computer-based diabetes self-management interventions to manage type 2 diabetes appear to have a small beneficial effect on blood glucose control, and the effect was largest in the mobile phone subgroup. Better designed and more targeted interventions are needed to improve other aspects of diabetes self-management.

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