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ORIGINAL ARTICLE

Digital Health Interventions for the Prevention of Cardiovascular Disease: A Systematic Review and Meta-analysis

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Abstract

Objective: To assess the potential benefit of digital health interventions (DHIs) on cardiovascular disease (CVD) outcomes (CVD events, all-cause mortality, hospitalizations) and risk factors compared with non-DHIs.

Patients and Methods: We conducted a systematic search of PubMed, MEDLINE, EMBASE, Web of Science, Ovid, CINHAL, ERIC, PsychINFO, Cochrane, and Cochrane Central Register of Controlled Trials for articles published from January 1, 1990, through January 21, 2014. Included studies examined any element of DHI (telemedicine, Web-based strategies, e-mail, mobile phones, mobile applications, text messaging, and monitoring sensors) and CVD outcomes or risk factors. Two reviewers independently evaluated study quality utilizing a modified version of the Cochrane Collaboration risk assessment tool. Authors extracted CVD outcomes and risk factors for CVD such as weight, body mass index, blood pressure, and lipid levels from 51 full-text articles that met validity and inclusion criteria.

Results: Digital health interventions significantly reduced CVD outcomes (relative risk, 0.61; 95% CI, 0.46-0.80; $P<.001$; $I^2=22\%$). Concomitant reductions in weight (−2.77 lb [95% CI, −4.49 to −1.05 lb]; $P<.002$; $I^2=97\%$) and body mass index (−0.17 kg/m^2 [95% CI, −0.32 kg/m^2 to −0.01 kg/m^2]; $P=.03$; $I^2=97\%$) but not blood pressure (−1.18 mm Hg [95% CI, −2.93 mm Hg to 0.57 mm Hg]; $P=.19$; $I^2=100\%$) were found in these DHI trials compared with usual care. In the 6 studies reporting Framingham risk score, 10-year risk percentages were also significantly improved (−1.24%; 95% CI, −1.73% to −0.76%; $P<.001$; $I^2=94\%$). Results were limited by heterogeneity not fully explained by study population (primary or secondary prevention) or DHI modality.

Conclusion: Overall, these aggregations of data provide evidence that DHIs can reduce CVD outcomes and have a positive impact on risk factors for CVD.

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Cardiovascular disease (CVD) is the primary cause of morbidity and mortality and is associated with markedly increasing health care costs in the United States.[1] Approximately 1 in 3 deaths can be attributed to CVD,[1,2] and more than 90% of CVD morbidity and mortality can be attributed to preventable risk factors.[3] According to 2012 statistics, poor diet, smoking, and lack of physical activity continue to account for an overwhelming majority of CVDs and death,[4] with the cost of CVD in the United States approaching $200 billion per year.[1] Moreover, the average hospitalization for acute coronary syndrome is estimated to cost roughly $20,000, with repeated events costing up to 2 and 3 times the original amount.[5] Clearly, better interventions to improve CVD prevention, both primary and secondary, are needed.

Internet and smartphone use has grown exponentially in the past decade, opening up the possibility that these increasingly prevalent technological tools could improve health. Digital health interventions (DHIs), including such modalities as telemedicine, Web-based strategies, e-mail, mobile phones, mobile applications, text messaging, and monitoring sensors, are the most recent iteration of an effort to shift health care burden outside the walls of medical institutions and improve individualized care through positive behavior change theory.[6] Although previous studies have suggested benefits of DHIs in focused areas such as smoking cessation,[7]

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behavior patterns,[8] physical activity,[9] hemoglobin A_{1c},[10] blood pressure,[11] and weight loss,[12] evidence concerning the benefit of DHIs on CVD risk factors, let alone CVD outcomes such as CVD events, hospitalizations, and all-cause mortality, is lacking. With nearly 50,000 health care–related apps now available for download[13] and numerous Internet-based DHI solutions available, the benefit of DHIs on CVD prevention and outcomes, both primary and secondary, merits reexamination.

The purpose of this systematic review and meta-analysis was to inclusively review randomized controlled trials (RCTs) and cohort studies incorporating DHIs for the prevention of CVD outcomes (CVD events including myocardial infarction, stroke, revascularization, hospitalizations, and all-cause mortality) and modification of risk factors for CVD such as weight, body mass index (BMI; calculated as the weight in kilograms divided by the height in meters squared), blood pressure, cholesterol and glucose levels, and Framingham risk score (FRS). Our aim was to establish the potential benefit of DHIs on both primary and secondary CVD prevention and identify future needs in DHI and CVD research.

PATIENTS AND METHODS

Data Sources and Searches

This systematic review was conducted in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.[14] We included all RCTs and observational/cohort studies published between January 1, 1990, and January 21, 2014, that examined any element of DHI (telemedicine, Web-based strategies, e-mail, mobile phones, mobile applications, text messaging, and monitoring sensors) and impact on CVD. We intentionally and broadly included any studies of adult patients seeking CVD prevention to present a comprehensive overview of DHI studies analyzing CVD outcomes (CVD events, hospitalizations, or all-cause mortality) and modification of risk factors for CVD such as weight, BMI, blood pressure, cholesterol and glucose levels, and FRS regardless of type of health care professional or health care setting. Control interventions included usual care following standard guidelines and could involve non-DHIs (such as paper instructions or telephone calls) or no active intervention beyond usual care. We excluded studies in which the intervention lasted less than a month in order to assess long-term impact and sustainability, studies that did not report any CVD risk factors, redundant studies that were repeated in the literature without new data presented, protocol manuscripts, reviews, studies including only usability or adherence data, pediatric studies, and studies in which the intervention involved the health care professional rather than the patient.

Our search strategy was performed with the assistance of a medical librarian and included the PubMed, MEDLINE, EMBASE, Web of Science, Ovid, CINAHL, ERIC, PsychINFO, Cochrane, and Cochrane Central Register of Controlled Trials databases over the specified dates. We included the following search terms: *mobile health*, *mobile*, *mhealth*, *digital health*, *eHealth*, *internet*, *telemedicine*, *web*, *smartphone*, *cardiovascular*, *cardiac*, *prevention*, *outcomes*, *mortality*, *morbidity*, *event*, *Framingham*, *blood pressure*, *weight*, *BMI*, *waist circumference*, *glucose*, *lipids*, *cholesterol*, *smoking*, *tobacco*, *quality of life*, *emergency department*, *visits*, *hospitalizations*, *rehospitalizations*, *office visits*, *phone calls*, *cost*, *cost of care*, and *ROI*. This strategy identified 574 relevant abstracts, and an additional 14 references were identified through bibliography searches and personal contacts (Figure 1). Most articles were in English, and those in Spanish, Polish, and German were translated for review.

Study Selection

Two reviewers (R.J.W., N.M.C.) assessed each of the identified abstracts. Full-text versions of potentially eligible studies, categorized for inclusion by either reviewer, were requested (n=73). The 2 reviewers worked independently to evaluate the full-text reports for study inclusion, and disagreements were reconciled by consensus. Agreement on study inclusion was high, with $\kappa = 0.92$.

Data Extraction and Quality Assessment

Extracted data included study participant demographic characteristics (age, sex, previous Internet use, education level, socioeconomic status, race, comorbidities, and baseline markers of CVD), the DHI they received (frequency, type, and duration), and the control intervention. The DHIs

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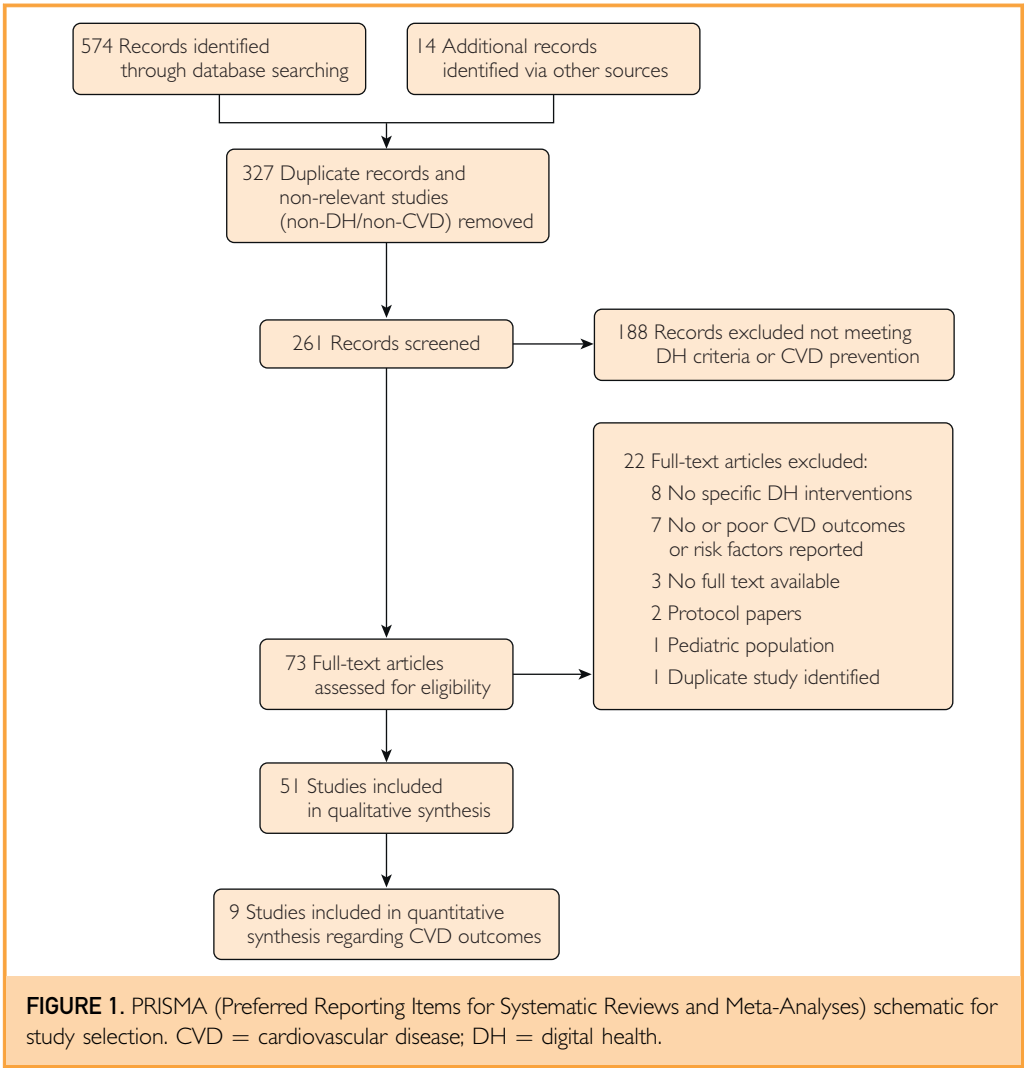

FIGURE 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) schematic for study selection. CVD = cardiovascular disease; DH = digital health.

were identified as involving telemedicine, Web-based strategies, e-mail, mobile phones, mobile applications, short message service (SMS) text messaging, and monitoring sensors. Control comparisons were heterogeneous and could include a non-DHI or usual care. The CVD outcomes included CVD events including myocardial infarction, stroke, revascularization, hospitalizations, and all-cause mortality. Risk factors for CVD included weight, BMI, blood pressure, cholesterol (total cholesterol, low-density lipoprotein [LDL] cholesterol, high-density lipoprotein cholesterol, and triglycerides) and glucose levels, and FRS.

Risk of bias and methodological quality were assessed independently by 2 authors (R.J.W., C.S.C.) using a modified version of the Cochrane Collaboration risk assessment tool[15] (Supplemental Figure 1, available online at http://www.mayoclinicproceedings.org). To evaluate the quality of nonrandomized studies, we assessed blinding of the outcome assessors to arm assignment in relationship to CVD outcomes and CVD surrogates, comparability of outcome assessment, and completeness of follow-up. The latter criteria followed a revised Newcastle-Ottawa quality assessment tool for observational studies[16] (Supplemental Figure 1) that emphasized proper definition of the CVD pertinent to the study, legitimate DHI, and reasonable follow-up. One study (Nolan et al[17]) was considered an observational study because the randomization scheme was compromised due to unintentional crossover of the participants, forcing the investigators to report the

data in separate, nonrandomized cohorts. Finally, a study by Wister et al[18] allowed separation of studies for primary and secondary prevention.

Statistical Analyses

When possible, we generated meta-analytic estimates of treatment effect using pooled relative risk (RR) and random-effects models. Analyses were performed using Review Manager (RevMan) version 5.2 software (Cochrane Collaboration). We measured heterogeneity for each outcome across studies using the I^2 test.[19] When SDs were missing for a study, imputation of the mean SD of the group for that particular variable was utilized in no more than 2 values per variable. Imputation of more than 2 SDs was not required for any analysis.

To explore causes of inconsistency in study findings and subgroup-treatment interactions, we planned subgroup analyses comparing results by patient population (primary prevention vs secondary prevention) and DHI subtype (telemedicine, Web-based modalities, e-mail reminders, SMS texting, mobile application, and data monitoring). Random effects methods utilizing Mantel-Haenszel methods for combining results across studies were undertaken as part of the RevMan 5.2 software package.[19] Sensitivity analyses controlling for workplace vs health care—delivered DHI were performed, as were sensitivity analyses removing the 2 observational, nonrandomized studies.

We contacted all authors with a prepopulated form including data for verification and missing data for their completion. Of the original 49 authors contacted, 28 returned correspondence with either verification of reported data or the addition of missing or incomplete data. There was no impact of the funding source on the design, execution, or analysis of the study.

RESULTS

Fifty-one studies met criteria for full-text review and were included in the systematic review, with 9 studies providing analyzable CVD outcome data. A summary of studies reporting CVD outcomes is presented in the Table.[20-28] Risk of bias among studies reporting CVD outcomes was predominantly low apart from a consistent lack of participant blinding (Figure 2) with a funnel plot included (Supplemental Figure 2, available online at http://www.mayoclinicproceedings.org).

Thirty-nine studies focused on primary CVD prevention (Supplemental Table 1, A, available online at http://www.mayoclinicproceedings.org),[17,18,20,24,29-63] and 13 studies primarily involved secondary CVD prevention (Supplemental Table 1, B)[18,21-23,25-28,64-68] (one study[18] fit into both categories separately). The total number of patients included was 24,054, with 13,495 assigned to DHI and 10,344 to control groups. The mean (SD) age for all of the participants in the studies was 54.0 years (9.4 years); most of the participants were white, and 54% were male. Five studies evaluated a solely female population, and 2 focused on only male participants. Socioeconomic status, geographic information, and prior Internet usage were not universally reported. Additionally, the time frame of a majority of studies was between 6 and 12 months, and most studies were published within the past decade. The RCTs were blinded, with specific mention of study personnel blinded to allocation and grouping during the study and to data analysis, with the exception of 3 studies.[26,50,57]

Cardiovascular disease outcomes including myocardial infarction, stroke, revascularization, hospitalizations, and all-cause mortality were abstracted from 9 RCTs (2 primary prevention studies, 2 involving patients with heart failure [HF], and 5 secondary prevention studies).[20-28] The 1267 participants in the DHI arms had 104 events, and the 996 participants in the usual care arms had 162 combined events. Overall, DHIs significantly reduced adverse CVD outcomes (RR, 0.61; 95% CI, 0.46-0.80; $P<.001$; $I^2=22\%$; Figure 3). Subgroup analyses revealed no interaction among the primary prevention (no prior CVD diagnosis), secondary prevention (known prior CVD diagnosis), and HF groups ($P=.11$). When the outcome "hospitalizations" was removed from the combined end point, there remained a 52% reduction in CVD events/deaths that was not statistically significant (RR, 0.48; 95% CI, 0.21-1.11; $P=.09$). In addition, DHI was associated with a significant reduction in Framingham 10-year risk percentages in the 6 studies reporting FRS data (−1.24%; 95% CI, −1.73% to −0.76%; $P<.001$; $I^2=94\%$).

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TABLE. Summary of 9 Randomized Controlled Trials Reporting Cardiovascular Disease Outcomes With Digital Health Interventions

Reference	Study duration (mo)	No. of patients		Study population	DHI	Findings
		Total	DHI			
Appel et al,[20] 2011	24	415	139	Primary prevention, hypertension	Web-based	Larger, health care site obesity intervention delivered remotely or in person significantly reduced weight (−4.6 kg and −5.1 kg, respectively) vs controls. No impact on CVD events, rehospitalizations, or all-cause mortality
Blasco et al,[21] 2012	12	203	102	Secondary prevention	SMS text, smartphone	Health care secondary prevention trial showing improved secondary prevention outcomes (repeated CVD events, rehospitalizations, or all-cause mortality; RR, 1.4; 95% CI, 1.1-1.7) with telemonitoring and SMS text
Dendale et al,[22] 2012	6	160	80	Secondary prevention, heart failure	Telephone, data monitoring	Health care–delivered telemonitoring service in patients with heart failure significantly reduced all-cause mortality (P=.01) but did not reduce hospitalizations per patient (0.24 vs 0.42; P=.06)
Frederix et al,[23] 2015	4.5	80	40	Secondary prevention	E-mail, SMS text, data monitoring	Body sensor data monitoring in patients undergoing cardiac rehabilitation improved exercise capacity (26.88±220.33 mL/min vs 285.89±385.44 mL/min; P=.014) and number of rehospitalizations
Green et al,[24] 2012	12	778	520	Primary prevention	Telephone, Web-based	In hypertensive patients assigned to usual care vs a Web-based or telephone-based intervention, those who used the Web-based platform had a greater percentage of achieving target BP (55% vs 39%; 95% CI, 49%-62%; P<.001). Increased adverse events occurred in intervention group
Reid et al,[25] 2012	12	223	115	Secondary prevention	Web-based	Internet-based data monitoring for physical activity in post-MI patients revealed significant improvements in physical activity and QOL compared with usual care. The intervention had a small, nonsignificant effect on hard CVD outcomes
Scherr et al,[26] 2009	6	120	54	Secondary prevention, heart failure	Telephone, SMS text, data monitoring	Data monitoring in patients with recent decompensated heart failure yielded a high attrition rate but a 50% reduction in CVD end points and hospitalizations with a mean improvement in NYHA class by one category in the treatment group
Southard et al,[27] 2003	6	104	53	Secondary prevention	Web-based	Internet-based secondary prevention tool reduced CVD end points (15.7% vs 4.6%) and provided a significant cost savings. The intervention group had a more robust weight loss (−3.68 lb vs 0.47 lb; P=.003), with no other surrogate markers of CVD achieving statistical significance
Vernooij et al,[28] 2012	12	330	164	Secondary prevention	Web-based	Clinic-based online risk factor improvement tool significantly reduced Framingham risk scores (−14%; 95% CI, −25% to −2%) after 12 mo in patients randomized to the intervention. No significant reduction in CVD events, death, and hospitalizations in the DHI group

BP = blood pressure; CVD = cardiovascular disease; DHI = digital health intervention; MI = myocardial infarction; NYHA = New York Heart Association; QOL = quality of life; RR = relative risk; SMS = short message service.

Effect of DHI in Primary Prevention Studies

Separate subgroup analyses of primary prevention studies (n=2) were unable to provide statistical evidence of a positive effect of DHI on CVD outcomes (RR, 1.21; 95% CI, 0.58-2.54; P=.61; I^2=15%; Figure 3). Eleven primary prevention studies reported a significant reduction in weight (−3.35 lb; 95% CI, −5.22 to −1.48 lb; P<.001; I^2=96%; Figure 4, A),[20,21,25,27,29-33,37,48,53,56,63,68] but 15 studies reported no significant reduction in BMI (mean difference, −0.11 kg/m^2; 95% CI, −0.30 to 0.08 kg/m^2; P=.26; I^2=98%; Figure 4, B).[18,21,24,27,28,31-35,40,41,44,48,55,56,60,67,68] When the 3 workplace intervention studies were removed from the pooled analysis, there was a significant reduction in BMI in primary prevention populations (n=12) (mean difference, −0.29 kg/m^2; 95% CI, −0.5 to −0.09 kg/m^2; P=.006; I^2=98%). We found

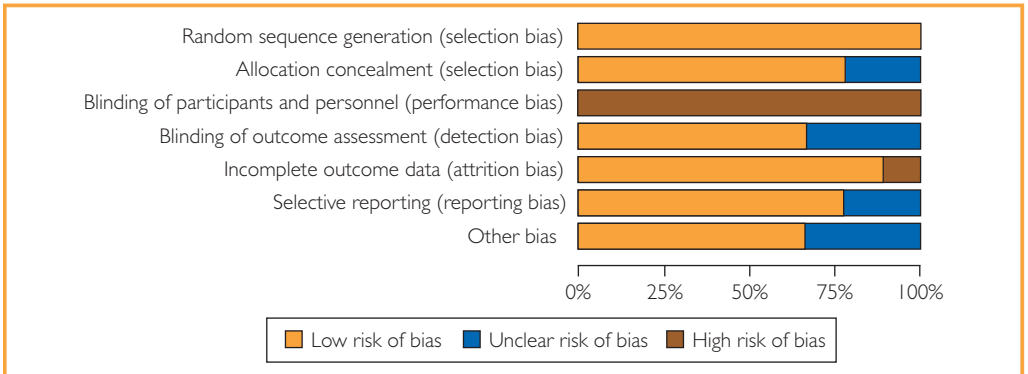

FIGURE 2. Risk of bias for outcomes studies. Assessment of risk of bias–based validity assessment tool (Supplemental Figure 1) used for the 9 studies with CVD outcomes analyzed. The x-axis represents the percentage of studies that were found to be of low (orange), unclear (blue), or high (brown) risk of bias.

a significant reduction in systolic blood pressure (SBP) among 23 primary prevention studies[17,18,21,23,27-29,31-35,37,40,44,47,49,50,52,53,56,57,59-61,63-65,68] (mean difference, −2.12 mm Hg; 95% CI, −4.15 to −0.09 mm Hg; P=.04; I^2=100%; Supplemental Figure 3, available online at http://www.mayoclinicproceedings.org) that failed to maintain a statistically significant reduction when 2 observational studies were removed in sensitivity analysis (mean difference, −1.31 mm Hg; 95% CI, −3.43 to 0.80 mm Hg; P=.22; I^2=100%).

There was insufficient evidence to support a positive impact on triglyceride levels (n=7) (mean difference, −9.06 mg/dL; 95% CI, −22.7 to 4.6 mg/dL; P=.19; I^2=99%); however, we found significant reductions in total cholesterol (n=13) (mean difference, −5.39 mg/dL; 95% CI, −9.80 to −0.99 mg/dL; P=.02; I^2=98%; Supplemental Figure 4, A),[17,18,32-35,37,45,48,53,57,60,63] LDL cholesterol (n=8) (mean difference, −4.96 mg/dL; 95% CI, −8.54 to −1.38 mg/dL; P=.007; I^2=95%; Supplemental Figure 4, B),[32-34,45,48,53,60,63] and glucose (n=6) (mean difference, −1.38 mg/dL; 95% CI, −2.13 to −0.63 mg/dL); P<.001; I^2=81%) in primary prevention populations.

Effect of DHI in Secondary Prevention Studies

Subgroup analyses of secondary prevention studies found a significant impact of DHI on CVD outcomes (RR, 0.60; 95% CI, 0.43-0.83; P=.002; I^2=0%; Figure 3). Pooled data from 4 secondary prevention trials[21,25,27,68] revealed no improvement in weight (−0.93 lb; 95% CI, −7.74 to 5.88 lb; P=.79; I^2=97%; Figure 4, A), but data from 6 studies revealed significant reductions in BMI[18,21,27,28,67,68] (mean difference, −0.31 kg/m^2; 95% CI, −0.60 to −0.03 kg/m^2; P=.03; I^2=67%; Figure 4, B). We found no improvement in SBP in secondary prevention DHI trials (mean difference, 1.98 mm Hg; 95% CI, −1.05 to 5.01 mm Hg; P=.20; I^2=94%; Supplemental Figure 3).

Similarly, there was no positive impact on triglyceride levels (n=5) (mean difference, −17.19 mg/dL; 95% CI, −49.45 to 15.07 mg/dL; P=.30; I^2=99%), total cholesterol (n=6) (mean difference, −1.80 mg/dL; 95% CI, −6.23 to 2.64 mg/dL; P=.43; I^2=94%; Supplemental Figure 4, A),[18,21,23,27,28,68] LDL cholesterol (n=5) (mean difference, −10.43 mg/dL; 95% CI, −21.69 to 0.83 mg/dL; P=.07; I^2=100%; Supplemental Figure 4, B),[21,23,27,28,68] or glucose (n=4) (mean difference, 0.45 mg/dL; 95% CI, −9.68 to 10.58 mg/dL; P=.93; I^2=100%) in secondary prevention populations.

Impact of Various DHI Modalities on Risk Factors for CVD

When we evaluated individual DHI modalities and their effects on risk factors for CVD, we found significant reductions in weight in studies that incorporated 3 modalities including Web-based DHIs (−3.18 lb; 95% CI, −5.61 to −0.75 lb; P=.01; I^2=98%; Figure 5, A),[20,25,27,30-33,37,53,68] telemedicine (−2.30 lb; 95% CI, −2.47 to −2.14 lb; P<.001; I^2=0%; Figure 5, B),[31-33] and SMS text messaging (−3.85 lb; 95% CI,

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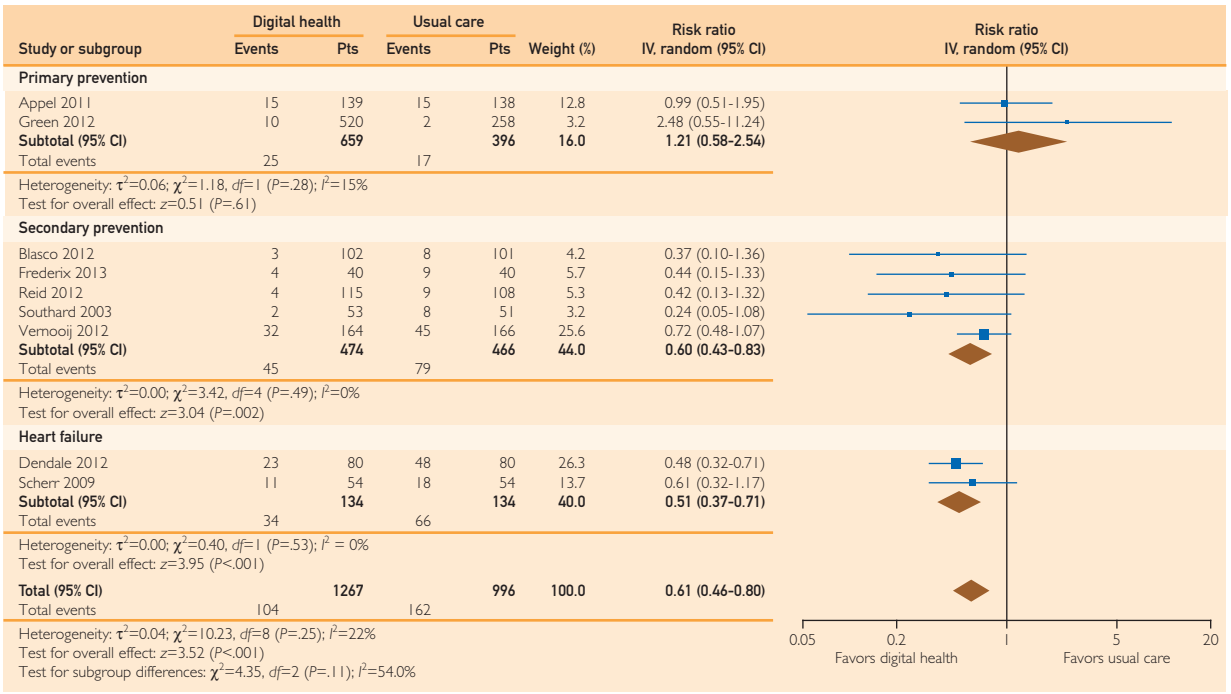

FIGURE 3. Cardiovascular disease outcomes in 9 randomized, controlled trials. Pts = patients.

−5.54 to −2.17 lb; $P<.001$; $I^2=83\%$; Figure 5, C),[21,48,53,63] with e-mail interventions having no significant reduction in weight (0.74 lb; 95% CI, −1.19 to 2.68 lb; $P=.45$; $I^2=0\%$; Figure 5, D).[29,56] Web-based modalities also had a beneficial impact on SBP (−2.63 mm Hg; 95% CI, −5.04 to −0.23 mm Hg; $P=.03$; $I^2=100\%$). Studies that incorporated data monitoring (n=5) reported no weight outcomes and found a significant benefit only in reducing diastolic blood pressure (−3.08 mm Hg; 95% CI, −4.8 to −1.36 mm Hg; $P<.001$; $I^2=0\%$).

DISCUSSION

This systematic review and meta-analysis reveals that DHI has a beneficial effect on CVD risk factors and outcomes. Applying an inclusive definition of DHI broadly applied to studies ranging from 2 to 36 months, we found a CVD morbidity and all-cause mortality benefit for secondary CVD prevention and HF groups, with primary prevention populations having benefit with regard to weight loss, BMI, SBP, total cholesterol, and LDL cholesterol. However, there was no clear benefit of DHI in primary prevention populations for CVD outcomes, although a reduction in FRS was seen in our pooled analyses. In subgroup analysis by DHI subtype, there was particular benefit seen for Web-based, telemedicine, and SMS texting DHI approaches, with insufficient data to support a benefit for e-mail DHI.

As noted previously, the literature on DHI and CVD-related outcomes has been limited. A recent systematic review of PubMed for mobile health and secondary CVD prevention over the prior 10 years identified 3 studies without any quantitative results.[69] Other systematic reviews have documented the efficacy of DHI on certain specific risk factors for CVD. Whittaker et al[7] reported improvements in smoking cessation across a wide variety of studies. Furthermore, additional work has found DHI to positively affect behavior patterns[8] and physical activity.[9] Liang et al[10] reported reductions of nearly 0.5% in hemoglobin A_{1c} in 22 studies evaluating mobile phone program or text messaging tactics for participants with diabetes. Uhlig et al[11] identified a favorable change in blood pressure at 6 months in 26 separate studies, yet they noted a lack of improvement in blood pressure at 12 months. A separate meta-analysis of 36 weight loss studies found that 71% of the studies reported some form of weight loss, although participant and

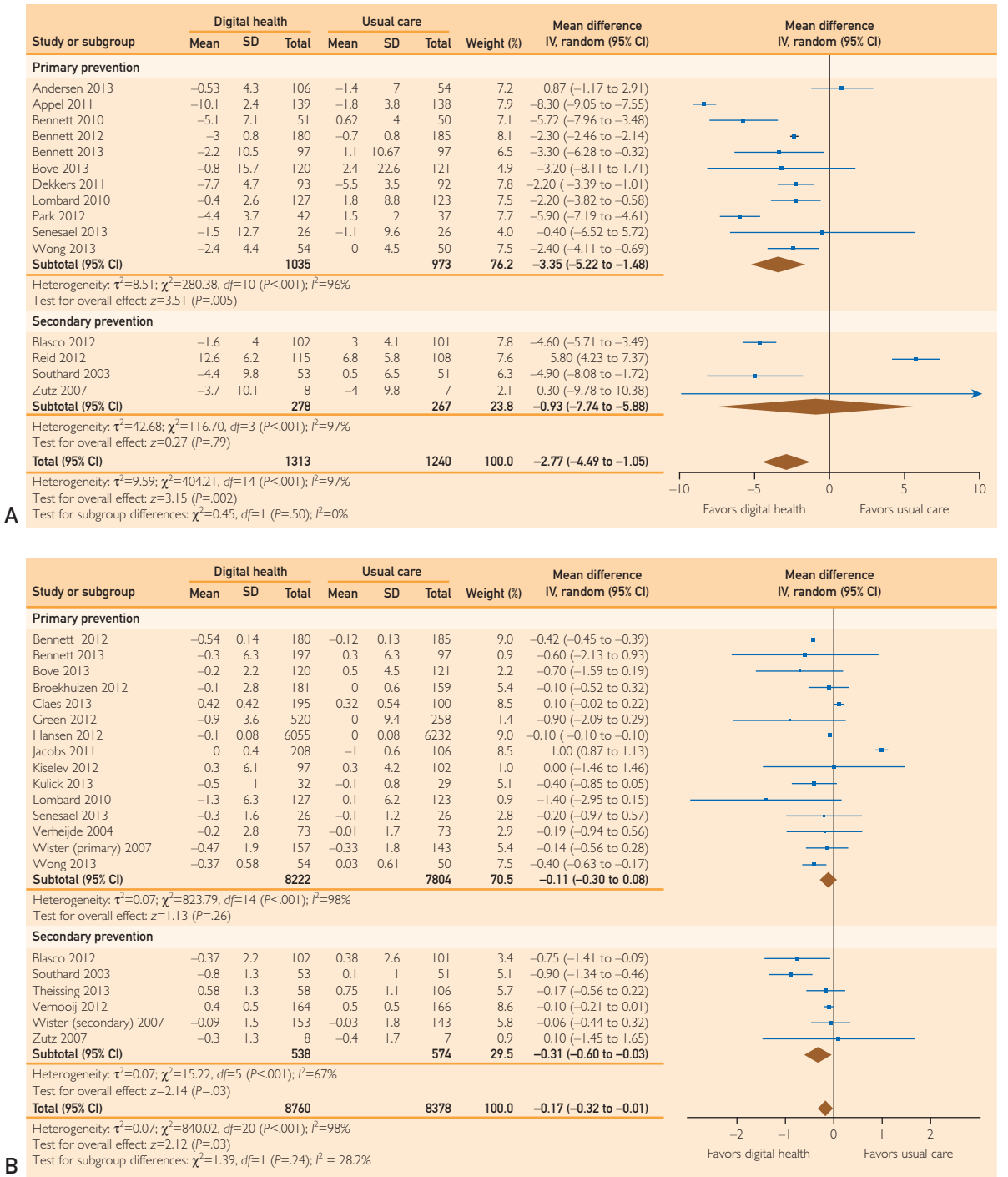

FIGURE 4. Effect of digital health interventions on weight (A) and body mass index (B).

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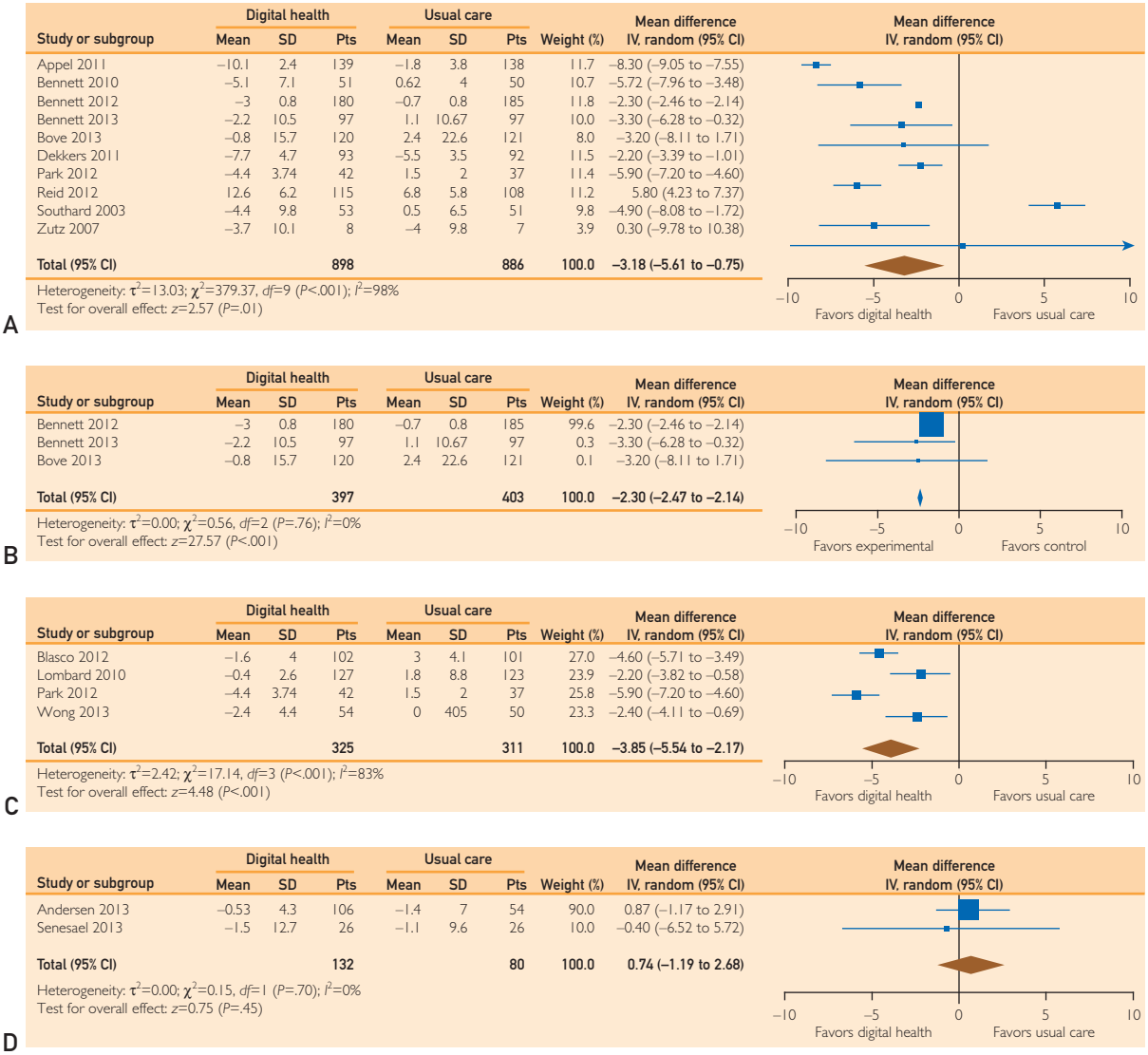

FIGURE 5. Effect of Web-based (A), telemedicine-based (B), short message service text-based (C), and e-mail–based (D) digital health interventions on weight loss.

intervention heterogeneity precluded a summary estimate of weight loss achieved through DHI.[12]

In this systematic review and meta-analysis, we noted a nearly 40% RR reduction in CVD outcomes with DHI, with particular impact on secondary CVD prevention and in patients with HF. This level of risk reduction surpasses other prevalent, guideline-based preventive measures such as statins,[70] aspirin,[71] or blood pressure reduction with β-blockade.[72] Furthermore, the absolute risk reduction in events was 6.5% in our pooled analysis and 7.5% in secondary prevention populations, based on extrapolations of our results. This translates into a number needed to treat of 14 and 16 patients, respectively, also surpassing reported absolute benefits of other guideline-based measures. Because DHI use does not directly reduce CVD risk, these observed benefits likely reflect increased adherence to evidence-based preventive therapies such as statins, aspirin, or β-blockers.

We found significant improvements in the risk factors of weight loss, BMI, blood pressure, and LDL cholesterol in patients seeking primary

prevention of CVD. These improvements in risk factors did not translate into an improvement in CVD outcomes in primary prevention studies, at least partly owing to lower-risk populations and lack of long-term follow-up. Conversely, we found significant reductions in these events in secondary prevention studies despite a lack of consistent reductions in CVD risk factors in secondary prevention studies. This heterogeneity in results is not readily explained by existing studies and should prompt future DHI research focusing on furthering our understanding of the variables determining success of specific DHIs in specific populations.

Our study has some limitations. In an attempt to be inclusive in assessing the impact of DHI on CVD, we collected data utilizing multiple DHI modalities applied in multiple populations. Therefore, as noted previously, heterogeneity in study results was present secondary to variation in study populations, DHI types, comparator groups, and lengths of follow-up. Heterogeneity in these analyses was not explained by DHI modality or study design. Despite this heterogeneity, the data reveal an overall benefit of DHI for CVD prevention. However, the observed level of heterogeneity precludes definitive conclusions regarding specific DHIs that should be clinically applied to CVD prevention at the present time.

In addition, this analysis was unable to assess behavior change and motivational techniques, either of which could impact the outcomes of trials or be a contributor to DHI efficacy. Research attempting to better assess these issues will be vital in future work. Despite these limitations, the existing studies confirm that technological advances such as DHI can have a positive impact on preventive cardiovascular medicine.

CONCLUSION

The data synthesized and analyzed in this systematic review show a net benefit of DHI on overall CVD outcomes (CVD events, hospitalizations, and all-cause mortality) compared with usual care. These gains are largely driven by improvements in CVD outcomes among higher-risk populations such as patients with HF or those targeting secondary CVD prevention. Digital health interventions were also associated with improvement in risk factors for CVD in primary prevention studies, suggesting the potential for positive impact of DHIs in a wide variety of participants and settings. Further research is needed to determine the most effective DHI modalities and to better understand the determinants of their success in specific cardiovascular risk populations.

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SUPPLEMENTAL ONLINE MATERIAL

Supplemental material can be found online at www.mayoclinicproceedings.org.

Abbreviations and Acronyms: **BMI** = body mass index; **CVD** = cardiovascular disease; **DHI** = digital health intervention; **FRS** = Framingham risk score; **HF** = heart failure; **LDL** = low-density lipoprotein; **RCT** = randomized controlled trial; **RR** = relative risk; **SBP** = systolic blood pressure; **SMS** = short message service

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