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Mobile phone text-messaging interventions aimed to prevent cardiovascular diseases (Text2PreventCVD): systematic review and individual patient data meta-analysis

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ABSTRACT

Background A variety of small mobile phone text-messaging interventions have indicated improvement in risk factors for cardiovascular disease (CVD). Yet the extent of this improvement and whether it impacts multiple risk factors together is uncertain. We aimed to conduct a systematic review and individual patient data (IPD) meta-analysis to investigate the effects of text-messaging interventions for CVD prevention.

Methods Electronic databases were searched to identify trials investigating a text-messaging intervention focusing on CVD prevention with the potential to modify at least two CVD risk factors in adults. The main outcome was blood pressure (BP). We conducted standard and IPD meta-analysis on pooled data. We accounted for clustering of patients within studies and the primary analysis used random-effects models. Sensitivity and subgroup analyses were performed.

Results Nine trials were included in the systematic review involving 3779 participants and 5 (n=2612) contributed data to the IPD meta-analysis. Standard meta-analysis showed that the weighted mean differences are as follows: systolic blood pressure (SBP), −4.13 mm Hg (95% CI −11.07 to 2.81, p<0.0001); diastolic blood pressure (DBP), −1.11 mm Hg (−1.91 to −0.31, p=0.002); and body mass index (BMI), −0.32 (−0.49 to −0.16, p=0.000). In the IPD meta-analysis, the mean difference are as follows: SBP, −1.3 mm Hg (−5.4 to 2.7, p=0.5236); DBP, −0.8 mm Hg (−2.5 to 1.0, p=0.3912); and BMI, −0.2 (−0.8 to 0.4, p=0.5200) in the random-effects model. The impact on other risk factors is described, but there were insufficient data to conduct meta-analyses.

Conclusion Mobile phone text-messaging interventions have modest impacts on BP and BMI. Simultaneous but small impacts on multiple risk factors are likely to be clinically relevant and improve outcome, but there are currently insufficient data in pooled analyses to examine the extent to which simultaneous reduction in multiple risk factors occurs.

PROSPERO registration number CRD42016033236.

Key questions

What is already known about this subject?

► A variety of small mobile phone text-messaging interventions have indicated improvement in risk factors for cardiovascular disease (CVD).

What does this study add?

► This is the first individual patient data meta-analysis showing the impact of text messaging on secondary prevention of CVD.

How might this impact on clinical practice?

► Text messaging is acceptable, generalisable and scalable and has modest impacts on multiple CVD risk factors with public health significance.

INTRODUCTION

Globally, deaths due to cardiovascular disease (CVD) have steadily increased over the last four decades,[1] with ischaemic heart diseases remaining as the single largest cause of death.[2] A large body of evidence has demonstrated that common and modifiable risk factors, including high blood pressure (BP), smoking, high cholesterol, obesity and physical inactivity, contribute substantially to the risk of CVD and premature death.[3–8] However, identifying low-cost, scalable and effective strategies to target all of these to prevent CVD and recurrent CVD events remains a major challenge.

In recent years, mobile health (mHealth) programmes have emerged as a strategy to support chronic health conditions. Much of the fervour around mHealth has been because of the potential seen to reduce socioeconomic disparity and to deliver a scalable low-cost intervention to a wide population and thus

alleviate the burden of CVD.[9] Two systematic reviews on mHealth interventions for secondary prevention of CVD reported that mHealth offers potential for improving CVD secondary prevention.[10 11] The 2018 review[7] included 9 (n=3637) studies using text messaging, and the 2016 study[8] included 28 studies (n=3820) using mHealth technologies (including text messaging, mobile apps and internet); neither of the reviews performed meta-analysis. The majority of studies showed the effectiveness of mHealth and text messaging in improving behaviours, patient satisfaction and clinical outcomes in patients with CVD. Text messaging and apps showed the highest user adherence and satisfaction compared with internet or continuous monitoring. The 2018 review concluded that text messaging might be a useful tool for secondary prevention of CVD, but conclusions were largely based on qualitative assessment of studies, and the 2016 review concluded that mobile phone features such as text messaging and apps have a strong potential to positively impact the secondary prevention of CVD. They suggested further research was needed to apply rigorous research designs with theory-based interventions, to measure economic benefits, process evaluation and adverse effects of the intervention, and were unable to address the frequency and content of text messaging and long-term impacts of the intervention on clinical outcomes and end points.

The global reach and ubiquity of mHealth interventions suggest they may be useful, but despite almost a decade of research, the evidence base remains limited. In this context, we performed a systematic review and meta-analysis of randomised controlled trials (RCTs) of text-messaging interventions used for the prevention of CVD risk factors to generate robust evidence and to identify researchers active in this field. We established the Text2PreventCVD Trial Collaborators Group, a global network of researchers working on mHealth interventions in CVD prevention and management, with the goals of collaboration to facilitate the next generation of trials. In the current paper, the Text2PreventCVD Collaboration aimed to quantify the extent of improvement in cardiovascular risk factors with mobile phone text-messaging interventions using systematic review and individual participant data (IPD) meta-analysis. Studies included needed to involve interventions that had the potential to impact on at least two measures of cardiovascular risk factors. The primary outcome designated for these analyses was systolic blood pressure (SBP) and the secondary outcomes included diastolic blood pressure (DBP) and body mass index (BMI).

METHODS

We performed a systematic review and IPD meta-analysis and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement and the Cochrane Collaboration reporting items for systematic reviews and meta-analysis guidelines.[12] This review is registered in the International Prospective Register of Systematic Reviews. The study protocol has been published previously.[13]

Search strategy

We searched MEDLINE, Embase, PsycINFO (Ovid) and the Cochrane Central Register of Controlled Trials for reports published from 1 January 1990 to 1 July 2016 to identify RCTs of text-messaging interventions used for the prevention of CVD risk factors. The following Medical Subject Headings search terms were used: (1) intervention (text messaging, text messages, short message service (SMS), text message mobile phone, cellular phone, texting, SMS); (2) CVD (heart disease, coronary disease, BP, hypertension, lipids, cholesterol, cardiovascular risk factors, myocardial infarction, vascular, diabetes and obesity) and (3) study design (RCT). We also searched for ongoing, recently completed and unpublished clinical trials meeting the inclusion criteria described earlier from different trial registers and reference lists of selected studies, and reviewed grey literature for any other relevant studies. Consultation and contacts with experts in the field were made to help identify relevant studies.

Study eligibility

Full details of the methods used have been reported previously.[13] In brief, studies were eligible if they were RCTs of a text-messaging intervention focused on CVD prevention (primary or secondary) with at least two behaviour change strategies, for example, physical activity and diet or BP lowering, smoking and cholesterol lowering[14]; study duration was at least 6 months and 70% completed the follow-up of participants; study participants were adults, the sample size was larger than 30 people, and the control group received standard care. Reports published in any language were considered.

Study selection and data extraction

Two researchers (SMSI and KS) independently screened titles and abstracts to identify studies meeting the inclusion criteria described previously. One researcher (SMSI) extracted and tabulated all relevant data in a predefined data extraction sheet and a second researcher (KS) checked it for accuracy. Extracted data included patient's baseline characteristics; the type and duration of the intervention; changes in SBP and DBP, BMI, weight and lipids; and any possible adverse outcome reported. Disagreement was resolved by consensus or in consultation with a third reviewer (CKC). Corresponding authors of the selected studies were invited to join the Text2PreventCVD Collaboration and to contribute data to the IPD meta-analysis.

Outcomes

The primary outcome was the difference between intervention and control groups in SBP at 6 months. However, as two studies[15 16] did not have complete SBP data at 6 months' follow-up, we performed the analysis based on end of follow-up data. We also sought to examine other measures of cardiovascular risk, including low-density lipoprotein (LDL) cholesterol, smoking, diet, quality of

life and physical activity. However, due to insufficient data availability, we were only able to conduct meta-analysis to analyse diastolic BP and BMI as secondary outcomes at the end of the follow-up period.

Assessment of study quality

Study quality was assessed using the Cochrane collaboration risk of bias assessment tool,[17] based on random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting and other bias.

Statistical analysis

Analyses were conducted in accordance with contemporary recommendations for IPD meta-analyses.[18–21] Primary and secondary outcome analyses were performed on the combined dataset using preferred one-stage IPD meta-analyses (ie, individual patient data (IPD) were pooled and then models run on the combined dataset).[20 22] The primary analyses consisted of a linear mixed model with the end-of-trial value as the outcome, the baseline value and the treatment arm as random effects, and a random trial intercept and random trial-by-treatment interaction. An interim meta-analysis (standard meta-analysis) of the systematic review was performed using both fixed and random-effects models to compare the results with the IPD meta-analysis. Sensitivity analyses included two-stage approaches using both random and fixed-effects meta-analyses, analysis of 6-month follow-up values as the outcome and excluding data from the heart exercise and remote technologies (HEART) study, which measured BP in the context of participants doing exercise. Subgroup analyses were performed using the one-stage IPD and fitting a subgroup and subgroup by treatment interaction fixed effect into the model so heterogeneity between subgroup categories (education, age and gender) could be assessed. All data analyses were carried out using STATA V.12 and SAS V.9.2.

RESULTS

Study characteristics

Out of a total of 1210 identified citations, nine trials consisting of 3779 participants met the inclusion criteria of our systematic search (figure 1). We contacted all nine study groups and five agreed to contribute data to the IPD meta-analysis described further. Characteristics of the nine trials are shown in table 1. The median sample size was 236 (range 123–1372) and the median intervention period was 6 months (range 6–24 months). The mean age of the participants was 54.1±5.5 years and 37.5% were women. The gender spread across the studies was broad from one study of 100% men[23] to one with <30%.[15] The trials included participants with a range of levels of absolute cardiovascular risk from primary prevention to secondary prevention populations. Of the nine trials included, one trial included 'normal' participants not on drug therapy,[23] with the others including

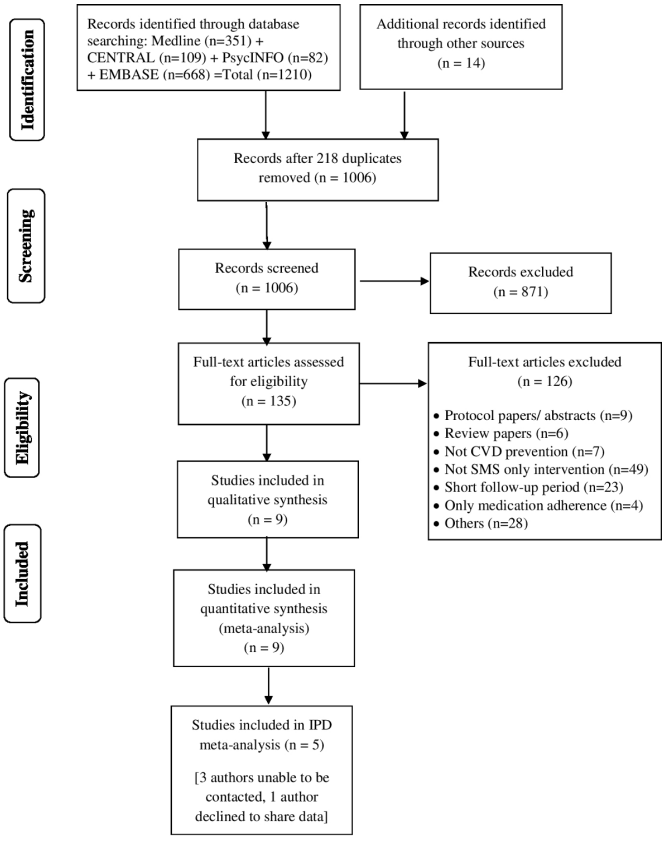

Figure 1 Study selection process. CENTRAL, Cochrane Central Register of Controlled Trials. CVD, cardiovascular disease; IPD, individual patient data; SMS, short message service.

patient populations selected on the basis of having a cardiovascular risk factor or CVD; for example, two studies included participants with high BP,[15 16] three with coronary heart diseases,[24–26] two with diabetes,[27 28] one included only working men with no diabetes[23] and one participant taking medication for either BP or lipid lowering.[29] Five studies recruited participants from hospital settings,[16 24–26 28] two from primary healthcare settings,[15 29] one from a hospital emergency department[27] and one in an industrial area work setting.[23] The duration of the text-messaging intervention was 6 months for seven studies,[24–29] 12 months for one[15] and 24 months for another.[23]

Text message intervention characteristics

There was considerable variation in the characteristics of the individual text-message interventions (see online supplementary table S1). Five studies provided text messages as a stand-alone intervention. Four studies provided additional support to participants in the form of telephone support[16 29] and via secure website.[25 26] Message frequency varied from one message per week up to two messages per day. Four studies sent text messages at a fixed predetermined frequency.[24 27–29] Most studies used unidirectional text messaging and three used interactive text messaging.[15 25 29] Six studies used personalised or semipersonalised text messages, while three studies used

Table 1 Characteristics of the study using text message intervention for CVD prevention

Author, year (trial)	Sample size Duration	Age (years)* Male (%)	Intervention versus control	Participant characteristics	Setting, country	Primary outcome	Secondary outcome
Arora *et al*, 2014 (TExT-MED)[27]	128 6 months	50.7±10.2 36	Text messages versus no text message	Patients with poorly controlled diabetes (HbA1c>8%)	Emergency department, LA County Hospital, University of Southern California, USA	Change in HbA1c	Medication adherence, self-efficacy, performance of self-care tasks, QoL, diabetes-specific knowledge, ED use and patient satisfaction.
Bobrow *et al*, 2016 (StAR)†[15 42]	1372 12 months	54.3±11.5 28	Usual care versus informational SMS versus interactive SMS	Patients treated for high BP	Single primary care centre in Cape Town, South Africa	Change in mean SBP from baseline to 12 months	Proportion of BP<140/90, medication adherence by PDC and self-report, QoL (EQ5D), clinic attendance and retention, satisfaction with clinic services and care, hospital admissions and basic hypertension knowledge
Chow *et al*, 2015 (TEXT ME)†[24 41]	710 6 months	57.9±9.1 81.5	Usual care versus text messaging+usual care	Patients with documented CHD	A large metropolitan tertiary referral public hospital in Sydney, Australia	Change in plasma LDL cholesterol at 6 months	Change in SBP, BMI, WC, total cholesterol, HR, smoking status, QoL (SF-12), medication adherence, physical activity, proportion achieving modifiable risk factors, PHQ-9 and nutritional status
Islam *et al*, 2015 (MPID)†[28 43]	236 6 months	48.1±9.7 45.8	Routine care versus SMS+routine care	Patients with type 2 diabetes on oral therapy	Tertiary hospital outpatient department, Dhaka, Bangladesh	Mean changes in HbA1c at 6 months	Medication adherence, QoL (EQ5D), physical activity, PHQ-9, BP, WC, BMI and diet
Kiselev *et al*, 2012[16]	199 12 months	50±11 55	Active ambulatory care management supported by SMS versus traditional ambulatory care management	Patients with arterial hypertension	Ambulatory department of the Saratov Research Institute of Cardiology, Saratov, Russia.	BP levels	BMI and smoking rates
Maddison *et al*, 2015 (HEART)†[26 31]	171 6 months	60.2±9.3 81	Mobile phone text messages and internet intervention plus usual care, or usual care alone	Adults with a diagnosis of IHD, able to perform exercise and who had access to the internet.	Two metropolitan hospitals in Auckland, New Zealand	Change in maximal oxygen uptake at 6 months	Physical activity (IPAQ), SBP, weight, waist:hip ratio, self-efficacy, QoL (SF-36 and EQ5D) and cost-effectiveness
Pfaeffli Dale *et al*, 2015 (Text4Heart)†[25 44]	123 6 months	59.5±11.1 81.3	Centre-based CR (usual care) versus text messages and a supporting website+usual care	Adults diagnosed with CHD	Two large metropolitan hospitals in Auckland, NZ	Proportion of participants adhering to healthy behaviours at 6 months	BP, lipid profile, weight, BMI, waist:hip ratio, self-efficacy, depression and medication adherence
Ramachandran *et al*, 2013[23]	537 24 months	46±4.7 100	Mobile phone messaging intervention or standard care	Working Indian men aged 35–55 years with BMI of ≥23 kg/m^2 with no diabetes or major illness	Public and private-sector industrial units in southeast India	Incidence of type 2 diabetes	BMI, WC, SBP, DBP, lipid profile, total dietary energy intake and physical activity score
Wald *et al*, 2014[29]	303 6 months	60 (54–68) 53.8	Text group versus no text group	Patients taking BP and/or lipid-lowering medications	7 Primary care practices in London, UK	Medication use at 6 months, exceeding 80% of the prescribed regimen	Proportion of patients continuing their medications, taking >80% of their prescribed regimen, BP, total cholesterol and LDL

*Age in years (mean±SD/median (IQR)).
†Studies included in the individual patient data meta-analysis.
BMI, body mass index; BP, blood pressure; CHD, coronary heart disease; CR, cardiac rehabilitation; CVD, cardiovascular disease; DBP, diastolic blood pressure; ED, emergency department; EQ5D, EuroQol Group 5-Dimension Self-report Questionnaire; HbA1c, haemoglobin A1c; IHD, ischaemic heart disease; LDL, low-density lipoprotein; PDC, proportion of days of medication covered; PHQ-9, Patient Health Questionnaire 9; QoL, quality of life; SBP, systolic blood pressure; SF-12, short form 12; SF-36, short form 36; SMS, short message service; StAR, SMS Text-message adherence suppoRt tria; TEXT ME, Effect of Lifestyle-Focused text messaging on risk factor modification in patients with coronary heart disease: a randomized clinical trial; TExT-MED, Trial to examine text message-based mHealth in emergency department patients with diabetes; WC, waist circumference.

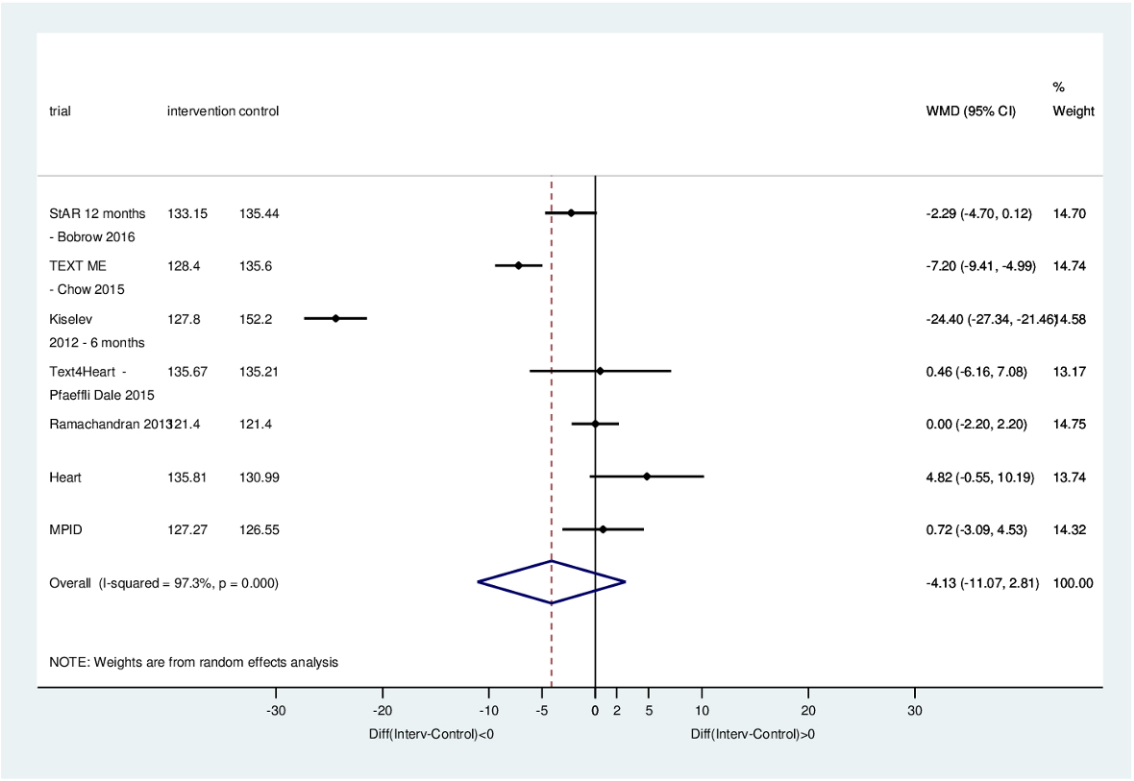

Figure 2 Standard meta-analysis at end follow-up on systolic blood pressure results (random-effects model). MPID, mobile phone intervention for diabetes; WMD, weighted mean difference.

generalised messages.[16 27 28] Message content was based on clinical guidelines (five studies), expert opinion (two studies) and feedback from formative qualitative work (three studies). The number of behaviour change strategies used ranged from 2 to 17. Seven studies reported patient feedback on the text messaging.[16 23–29]

Standard meta-analysis of the intervention efficacy

Of the 3779 participants, 295 did not have complete data and were excluded from the analysis. In the pooled analysis of 3348 patients, using a random-effects model, text message intervention significantly reduced SBP at the end of follow-up (weighted mean difference −4.13 mm Hg (95% CI −11.07 to −2.81, p=<0.0001) (figure 2). There was high heterogeneity (I^2 97.3%) across the clinical trials due to one study with a large effect size.[16] The weighted mean difference in DBP was −1.11 mm Hg (95% CI −1.91 to −0.31, p=0.002, I^2 77.2%) and BMI was −0.32 (95% CI −0.49 to −0.158, <0.0001, I^2 91.5%).

IPD meta-analysis of the intervention efficacy

The IPD meta-analysis involved five studies with 1976 participants from Australia, Bangladesh, New Zealand and South Africa (table 2). The mean difference in SBP at the end of the follow-up period was −1.3 mm Hg (95% CI −5.4 to 2.7, p=0.5236, I^2 89.0%) in the random-effects model. The mean differences in DBP and BMI were −0.8 mm Hg (95% CI −2.5 to 1.0, p=0.3912, I^2 77.2%) and −0.2 mm Hg (95% CI −0.8 to 0.4, p=0.5200, I^2 91.5%), respectively, at the end of the follow-up using the random-effects model (table 3).

Other CVD risk factors

Three studies[25 27 28] included in the standard meta-analysis reported effects of text messaging on medication adherence using Morisky's eight-item medication adherence scale (MMAS-8).[30] These studies showed improvement in the MMAS-8 score to a varying degree 1.1 (95% CI 0.1 to 2.1), −0.11 (95% CI −0.49 to 0.26) and 0.58 (95% CI 0.19 to 0.97). Three studies measured changes in LDL cholesterol, but data were presented in reports for only two studies −0.11 mg/dL (95% CI −0.49 to 0.26, p=0.04)[24] and −0.25 mg/dL (95% CI −0.49 to 0.01, p=0.053).[25] Two studies reported changes in glycated haemoglobin with a mean difference of −0.45% (p=0.230)[27] and −0.64% (−0.95 to −0.33).[28]

With respect to whether interventions impacted on multiple cardiovascular risk factors, four studies[15 23 24 28] showed statistically significant reductions in two or more cardiovascular risk factors, while two studies[27 31] reported improvements (not statistically significant) in two or more cardiovascular risk factors at the end of the study (see online supplementary table S5). One study reported concurrent reductions in LDL cholesterol, BP, BMI, physical activity and smoking, with 28.9% achieving at least four guideline levels of cardiovascular risk factors in the intervention group, compared with 10.3% in the control group and 4.7% achieving all five guideline levels in the intervention group, compared with 1.8% in the control group.[24]

Sensitivity analysis

A sensitivity analysis was conducted in which data from the HEART trial[26] were excluded, mainly because BP

Table 2 Trials included in the individual patient data meta-analysis with outcomes by trial at the end of follow-up*

Trial	Location	Participants	Outcome	n	Intervention	Control	Mean difference (95% CI)	P value for the difference
Systolic blood pressure (mm Hg) at end of follow-up								
HEART[31]	New Zealand	IHD	Number of observations	152	74	78		
			Analysis of covariance		135.7 (132.7 to 138.6)	131.1 (128.3 to 134.0)	4.6 (0.5 to 8.7)	0.0289
MPID[28]	Bangladesh	Diabetes	Number of observations	236	118	118		
			Analysis of covariance		127.1 (124.8 to 129.4)	126.7 (124.4 to 129.0)	0.4 (–2.8 to 3.7)	0.7968
StAR[15]	South Africa	Hypertension	Number of observations	802	406	396		
			Analysis of covariance		133.2 (131.7 to 134.8)	135.4 (133.8 to 136.9)	–2.1 (–4.3 to 0.1)	0.0599
Text4Heart[25]	New Zealand	CHD	Number of observations	114	56	58		
			Analysis of covariance		135.5 (130.9 to 140.1)	135.4 (130.8 to 139.9)	0.1 (–6.4 to 6.6)	0.9800
TEXT ME[24]	Australia	CHD	Number of observations	672	329	343		
			Analysis of covariance		128.2 (126.7 to 129.8)	135.8 (134.3 to 137.3)	–7.6 (–9.8 to –5.4)	<0.0001
Diastolic blood pressure (mm Hg) at the end of follow-up								
HEART[31]	New Zealand	IHD	Number of observations	152	74	78		
			Analysis of covariance		79.3 (77.4 to 81.3)	77.7 (75.8 to 79.6)	1.6 (–1.1 to 4.4)	0.2483
MPID[28]	Bangladesh	Diabetes	Number of observations	236	118	118		
			Analysis of covariance		79.1 (77.9 to 80.4)	78.2 (76.9 to 79.4)	1.0 (–0.8 to 2.8)	0.2844
StAR[15]	South Africa	Hypertension	Number of observations	802	406	396		
			Analysis of covariance		82.9 (81.9 to 84.0)	84.0 (83.0 to 85.1)	–1.1 (–2.6 to 0.4)	0.1497
Text4Heart[25]	New Zealand	CHD	Number of observations	114	56	58		
			Analysis of covariance		79.4 (76.8 to 82.0)	79.6 (77.1 to 82.1)	–0.2 (–3.8 to 3.4)	0.9019
TEXT ME[24]	Australia	CHD	Number of observations	673	329	344		
			Analysis of covariance		80.5 (79.6 to 81.5)	83.6 (82.7 to 84.5)	–3.1 (–4.4 to –1.7)	<0.0001
BMI (kg/m^2) at the end of follow-up								
HEART[31]	New Zealand	IHD	Number of observations	152	74	78		
			Analysis of covariance		28.7 (28.4 to 28.9)	28.5 (28.2 to 28.7)	0.2 (–0.1 to 0.5)	0.2569
MPID[28]	Bangladesh	Diabetes	Number of observations	163	90	73		
			Analysis of covariance		26.5 (25.9 to 27.1)	26.0 (25.4 to 26.7)	0.4 (–0.5 to 1.3)	0.3425
StAR[15]	South Africa	Hypertension	Number of observations	795	401	394		
			Analysis of covariance		33.5 (33.3 to 33.7)	33.7 (33.5 to 33.9)	–0.1 (–0.4 to 0.2)	0.3732
Text4Heart[25]	New Zealand	CHD	Number of observations	113	55	58		
			Analysis of covariance		29.1 (28.8 to 29.4)	29.2 (28.9 to 29.5)	–0.1 (–0.6 to 0.3)	0.6015

Continued

Table 2 Continued

Trial	Location	Participants	Outcome	n	Intervention	Control	Mean difference (95% CI)	P value for the difference
TEXT ME[24]	Australia	CHD	Number of observations	684	335	349		
			Analysis of covariance		29.0 (28.8 to 29.3)	30.3 (30.1 to 30.5)	−1.3 (−1.6 to −0.9)	<0.0001

Note: All randomised patients with both visits assessed at baseline and at the end of follow-up have been included in this analysis.
End of follow-up corresponds to month 12 for StAR study and month 6 for other studies.
Primary analysis—non-adjusted model: analysis of covariance including randomised treatment and baseline value.
n is the total number of observations used (available) for the analysis at month 6 using baseline value as covariate.
CHD, coronary heart disease; IHD, ischaemic heart disease; MPID, mobile phone intervention for diabetes; StAR, Mobile Phone Text Messages to Support Treatment Adherence in Adults With High Blood Pressure (SMS-Text Adherence Support); TEXT ME, Effect of Lifestyle-Focused text messaging on risk factor modification in patients with coronary heart disease; TExT-MED, Trial to examine text message-based mHealth in emergency department patients with diabetes.

was measured in the context of cardiopulmonary exercise testing. As a result, reductions were found for SBP −3.7 mm Hg (95% CI −5.1 to −2.3), DBP −1.6 mm Hg (95% CI −2.5 to −0.7) and BMI −0.5 (95% CI −0.7 to −0.3) (see online supplementary table S2).

Effects stratified by subgroup analysis

To further assess the impact of text messages, we performed an analysis based on participant characteristics. The moderators assessed were education (<12 years vs ≥12 years), age (<60 years vs ≥60 year) and gender (male vs female). There was no significant variation in the effectiveness of text message intervention by strata (see online supplementary table S3).

Study quality

We assessed the study quality as per Cochrane guidelines[12] (see online supplementary table S4). All studies described a randomisation sequence generation technique that was at low risk of bias except one that had an unclear risk of bias.[16] Three studies did not report allocation concealment and were categorised as unclear allocation concealment.[16 23 27] Blinding of study participants was not possible due to the nature of intervention for any of the studies. Blinding of outcome assessments was not clearly described in four studies.[16 25 27 29] Six studies were reported to have low incomplete outcome data,[15 23–27 29] one with unclear outcome data[28] and one with high incomplete outcome data.[16] All studies scored low in selective reporting and other bias, while only one study had unclear other bias.[16] Overall, 7 (78 %) studies were thought to be of high quality with a maximum of one unclear assessment.[15 23–26 28 29] Publication bias could not be assessed as the number of trials was few.

Text message acceptability

Participant feedback on text-message acceptability was reported in seven studies[16 23–28] (see online supplementary table S2). Most studies reported moderate to high levels of satisfaction with the text-messaging programme. Participants acknowledged text-message support as a useful and expressed desire to programme continuation. In one study,[28 32] participants were willing to pay a small fee to receive the text-messaging programme. In one study, a small fraction (3%) of the participants felt that the messages were disturbing.[23]

DISCUSSION

The main findings of this paper is that mobile phone text-messaging interventions have modest impacts on objective measures of cardiovascular risk factors of BP and BMI in analyses of pooled data using standard and IPD meta-analyses. Modest impacts on cardiovascular risk factors could have clinical and/or public health significance if they could impact on multiple risk factors simultaneously and/or do this at a very low cost, but the current data are not conclusive on these points. The pooled data are from a number of different regions, and the high

Table 3 Individual patient data meta-analysis at the end of follow-up*

Outcome	Model	Intervention	Control	Mean difference (95% CI)	P value for the difference
SBP	Random-effects model (1a)	132.1 (128.7 to 135.5)	133.4 (130.0 to 136.8)	−1.3 (−5.4 to 2.7)	0.5236
	Fixed-effects model (2)	131.3 (130.2 to 132.4)	134.3 (133.2 to 135.4)	−3.1 (−4.4 to −1.7)	<0.0001
DBP	Random-effects model (1a)	80.9 (79.4 to 82.4)	81.7 (80.2 to 83.2)	−0.8 (−2.5 to 1.0)	0.3912
	Fixed-effects model (2)	80.6 (79.8 to 81.3)	81.9 (81.2 to 82.6)	−1.3 (−2.2 to −0.5)	0.0018
BMI	Random-effects model (1b)	30.6 (30.2 to 31.1)	30.8 (30.4 to 31.3)	−0.2 (−0.8 to 0.4)	0.5200
	Fixed-effects model (2)	30.5 (30.3 to 30.7)	31.0 (30.8 to 31.1)	−0.5 (−0.7 to −0.3)	<0.0001

Note: All randomised patients with both visits assessed at baseline and at month 6 have been included in this analysis.
Primary analysis—analysis of covariance, including randomised treatment and baseline value as fixed effect: model 1: (a) includes trial random effect and random treatment by trial interaction, (b) includes trial fixed effect and random treatment by trial interaction when model 1a estimates trial random effect to zero; model 2: only fixed effects, including trial effect; model 3: sensitivity analysis pooling the estimates from the five trials using a standard meta-analysis checking for data heterogeneity between trials.
*For the StAR study, 12 month data was used for follow-up. For all other studies, 6 month data was used for follow-up.
BMI, body mass index; DBP, diastolic blood pressure; SBP, systolic blood pressure.

acceptability of texting interventions reported by most studies in our review suggests generalisability of findings and potential for widespread implementation, but there is still relatively few large-scale or multicentre evaluations.

Efficient, simultaneous risk factor reduction is important in the prevention of CVD as risk reduction is additive across single risk factors; for example, BP lowering plus lipid lowering is more effective at reducing risk than either alone. The reasons that the data are still inconclusive are likely because of the small number of individual participants in trials, the heterogeneity of the study population (including primary and secondary prevention populations), the heterogeneity of the interventions and the likely small individual impact of the interventions themselves.

Mobile phone text messaging might be a low-cost intervention, but data on cost-effectiveness are still limited. One of the studies included had a published cost-effectiveness study that modelled implementation of the text-message intervention to a target population of 50 000 patients with coronary heart disease; the intervention was estimated to lead to 563 fewer myocardial infarctions, 361 fewer strokes and 1143 additional quality adjusted life years, and was associated with an overall saving of $10.56 million for the health system over the patients' lifetimes.[33]

There have been some previous systematic reviews in mHealth interventions for CVD secondary prevention. One recent systematic review of mobile phone interventions for secondary prevention of CVD reported that text messaging was effective in improving clinical outcomes better than smartphone-based interventions.[11] The study discussed that incorporating principles of behavioural change may help promote and sustain healthy lifestyle behaviours in patients with CVD, resulting in better outcomes.[11] Another systematic review of mobile phone text messaging for improving secondary prevention in CVD suggested that text messaging might be beneficial for secondary prevention of CVD but failed to draw reliable conclusions.[10] A 2017 systematic review identified six studies using text messaging for hypertension management but did not perform meta-analysis due to variation in the studies.[34] The study concluded that text messaging had strong potential for innovation in hypertension management, especially in minority groups and those with low access to healthcare services. All these systematic reviews suggested that text messaging might have a role in secondary prevention of CVD but could not quantify effectiveness due to a lack of meta-analysis. Our study is therefore unique as it used IPD as well as meta-analysis.

The main mechanism by which texting intervention appear to work is via behavioural change. All trials included in our review incorporated two or more behaviour change theories. Behaviour change interventions and techniques, including motivational interviewing,[35] increasing patient motivation and self-efficacy,[36] goal setting combined with self-monitoring of behaviour,[37] supporting medical adherence and multimodal behavioural interventions, have been highlighted as effective in various CVD prevention programmes.[38 39] Text messaging offers confidential and unobtrusive support, which is an advantage over other interventions.

Strengths and limitations

The primary limitation of this meta-analysis was the differences in participants' characteristics, risk factor measurements and primary outcomes of interest across studies. A potential limitation is the small number of trials and a highly significant study included in the meta-analysis,[16] potential publication bias and influence of heterogeneity is possible. Of the nine trials included in the standard meta-analysis, we were only able to obtain full datasets from five trials. Also, we calculated the effect estimate from available data from published studies, and it is thus possible that bias can be introduced from differential loss to follow-up. Therefore, the results of this IPD meta-analysis cannot be generalised across different populations and should be interpreted with caution. Finally, the meta-analysis is not a

mechanistic study; thus, we cannot determine whether the benefit associated with the use of text messaging was attributable to BP lowering or to other mechanisms.

The primary strength of this meta-analysis was its systematic search to identify potential studies and the inclusion of only RCTs, which are less subject to bias and confounding than observational studies. The IPD analysis approach used in this study has advantages over a meta-analysis because the outcomes can be matched between studies and all studies are then analysed in the same prespecified statistical model. The use of data from many studies with different inclusion criteria should make the findings more generalisable, and the robustness of the main conclusions to subsidiary methods of analysis further supports the conclusion drawn.

Future research

There are still a number of unanswered questions that we were unable to adequately address, for example, whether different characteristics of the texting interventions influenced outcomes (ie, number of behaviour change techniques used, unidirectional vs bidirectional, high vs low frequency, personalised vs non-personalised). How can effects be maintained into the longer term and how are interventions best scaled up to populations? Future studies should address these questions, as well as the potential of these interventions in varied socioeconomic groups, age groups and cultures. Variations in effectiveness of behavioural interventions have been shown by gender.[37 40]

In addition, substantial variability exists with regard to the definitions of outcome measures for the different cardiovascular risk factors across studies. A standardised method for measuring the different outcomes in CVD prevention is warranted to improve comparability of outcome measures across studies for a more rigorous and reliable evaluation of the effectiveness of mHealth interventions for CVD.

CONCLUSION

Mobile phone text-messaging interventions have modest impacts on objective measures of BP and BMI. Evidence is suggestive, but inconclusive, that texting is acceptable, generalisable and scalable, and their modest impacts on cardiovascular risk factors may apply to multiple cardiovascular risk factors and hence make this a mHealth solution with public health significance.

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