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Mobile Phone Interventions for the Secondary Prevention of Cardiovascular Disease

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Abstract

Mobile health in the form of text messaging and mobile applications provides an innovative and effective approach to promote prevention and management of cardiovascular disease (CVD); however, the magnitude of these effects is unclear. Through a comprehensive search of databases from 2002–2016, we conducted a quantitative systematic review. The selected studies were critically evaluated to extract and summarize pertinent characteristics and outcomes. A large majority of studies (22 of 28, 79%) demonstrated text messaging, mobile applications, and telemonitoring via mobile phones were effective in improving outcomes. Some key factors associated with successful interventions included personalized messages with tailored advice, greater engagement (2-way text messaging, higher frequency of messages), and use of multiple modalities. Overall, text messaging appears more effective than smartphone-based interventions. Incorporating principles of behavioral activation will help promote and sustain healthy lifestyle behaviors in patients with CVD that result in improved clinical outcomes.

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Keywords

Cardiovascular disease; mobile health; text messaging; mobile applications; mobile phone; systematic review

As the leading cause of death globally, cardiovascular (CV) disease (CVD) claims more lives than all forms of cancer combined.[1,2] Global deaths from CVD increased by 41% between 1990 and 2013 as a result of population growth and aging as well as epidemiologic changes in disease.[3] CVDs are disorders of the heart and blood vessels including coronary heart disease (CHD), cerebrovascular disease, hypertension (HTN), heart failure (HF), valvular heart disease (VHD), congenital heart disease, and peripheral artery disease (PAD).[2,4] In patients with established CVD, secondary prevention includes comprehensive risk factor management that can be assessed by different outcomes such as improved survival, reduced recurrent events, reduced need for revascularization procedures, and improved quality of life.[5] Compelling evidence has described the importance of secondary prevention interventions in our growing problem of CVD worldwide. However, self-management is often challenging because of the complexity of medication regimens; the importance of self-monitoring for signs and symptoms of disease complications; and difficulty in making lifestyle behavior changes (i.e. physical activity/PA, diet, smoking cessation, and weight loss).[6]

Unlike traditional approaches of behavioral change interventions,[7] we can now leverage advancements in mobile technology to examine their efficacy in improving behavioral and clinical outcomes. In this new era of near-ubiquitous mobile phone ownership worldwide,[8,9] mobile health (mHealth) technologies offer unprecedented potential in disease prevention and self-management of chronic disease.

In the recent decade, mobile phones have been introduced as a potentially effective mechanism to promote behavior change in the secondary prevention of chronic disease. Mobile phone technology offers a personalized and inexpensive venue for patient communication, engagement, personal health data tracking, up-to-date information, and reminders for health behaviors. While the best way to promote self-management of chronic disease among patients has continued to elude health care providers, the use of technology may provide an innovative and effective approach to promote prevention and management of CVD.

Text messaging [or short-messaging service (SMS)] and mobile applications (apps) are two popular forms of mHealth that can be used to communicate with patients. Text messaging is more widely used by all age groups; however, mobile apps offer many more features than SMS and can harness the full sensing and computational capacity to collect and analyze health-related data in real time to deliver health and behavioral interventions.[10,11] In comparison to text messaging, mobile apps can offer interactivity, gaming, and feedback. In the past decade, there has been great interest in using mobile apps for promoting health and fitness. A majority of mobile phone users are interested in using mHealth apps.[12] There are now over 165,000 health-related mobile apps available to consumers.[13] However, most commercially available mobile apps are not rooted in evidence-based practices,[13–16] and there have been few studies on the use of mobile apps for prevention and management of CVD.[17]

The purpose of this paper is to review studies that have used mobile phone interventions to promote self-management of existing CVD (secondary prevention of CVD). In particular, we will explore the use of text messaging and mobile apps as single or combined technologies (mobile phones, tablets, Internet) for all CV conditions. Our aim is to identify the potential of mobile phones features to be used as effective interventions in the secondary prevention of CVD.

Methods

A comprehensive search was conducted to identify all studies related to the use of mobile phone interventions for CV health – including text messaging and mobile apps. Studies from all countries and languages, published in English, were included in the review. Searches were performed using PubMed, CINAHL, PsycINFO, and Cochrane from January 2002 to January 2016 to identify relevant research publications. The search terms included 'smartphone,' 'mobile phone,' 'cellular phone,' 'mobile health,' 'text messaging,' 'text message,' 'short messaging service,' 'SMS,' 'mobile app,' or 'mobile application' and were used in conjunction with the following terms: 'cardiac rehabilitation,' 'secondary prevention,' 'cardiovascular,' 'heart disease,' 'coronary artery disease,' 'cerebrovascular disease,' 'hypertension,' 'heart failure,' 'valvular heart disease,' 'congenital heart disease,' and 'peripheral arterial disease.' Furthermore, bibliographies from related systematic reviews and articles were reviewed to identify additional applicable studies (Figure 1).

The inclusion criteria included studies using text messaging and/or mobile app with mobile phones for the secondary prevention of CVD. We considered CVD studies as those addressing CHD, cerebrovascular disease, HTN, HF, VHD, congenital heart disease, and PAD. Although the primary search concentrated on mobile phone use, we included studies using text messaging and/or mobile app technologies in combination with other technologies such as the Internet. Studies were excluded if interventions were predominately conducted via voice phone calls (i.e. interactive voice response calls), email, Internet, or telemonitoring devices without the use of mobile phones. We excluded studies that did not target CVD disease management such as interventions limited to addressing PA, obesity, smoking cessation, or diabetes mellitus. No studies were disqualified on the basis of quality.

This review encompasses all study designs, including randomized controlled trials (RCT), quasi-experimental studies, observational cohort studies, and pilot studies, with the intent to gain broad coverage of the emerging mHealth field. Data were extracted from eligible studies including: location, CV condition, outcome, mHealth modality, design, sample characteristics, exposure of experimental and control groups, duration of intervention, and results. The included studies varied significantly in patient population, CV condition, intervention, and measurement of effectiveness. Investigators measured study outcomes either objectively or subjectively for evaluation of intervention efficacy. To account for variance, the efficacy of each study was assessed in the context of improved CV outcomes.

The search and assessment of studies were completed by independent reviews of the authors who addressed any discrepancies in their results until consensus was met.

Results

We identified a total of 28 studies that applied mobile phone interventions for CVD management through a comprehensive literature search (Table 1). Overall, 22 of the 28 studies (79%) demonstrated that using mobile phone features (text messaging, mobile apps, telemonitoring via mobile phones) was effective in improving behavioral and clinical outcomes. This review includes studies targeting a variety of CV conditions: CHD (12),[18–29] chronic HF (6),[30–35] HTN (5),[36–40] stroke (2),[41–42] acute coronary syndrome (1),[43] CVD (1),[44] and metabolic syndrome (1).[45] A dominant number of studies examined medication adherence as the clinical outcome (10 studies) while other studies examined outcomes such as PA, cardiac rehabilitation (CR) adherence, or a combination of CVD risk factors (blood pressure/BP, cholesterol, body mass index, weight). Four RCTs and one observational study examined major clinical outcomes in HF, CHD, and stroke but they did not find significant differences in mortality, number of hospitalizations, or days in hospital between the experimental and control groups.[28,30,33–35]

The majority of studies (18 out of 28, 64%) used text messaging as the intervention. Twelve out of 28 studies (43%) applied smartphone technology. In particular, seven studies used smartphones for data acquisition / transmission in telemonitoring programs [30,32–35,38,45] Five studies tested a smartphone app as the primary intervention.[23,27–29,42] In addition, there were seven studies that used multiple modalities to deliver the interventions including text messaging, mobile apps, Internet, and email.[18–19,21–23,25,27] Eighteen studies assessed patients' experiences with using mobile phones for health-related outcomes, and all studies reported high satisfaction, feasibility, and acceptability.

Six studies had null findings. The first study used a text messaging intervention through a randomized cluster study of physicians treating hypertensive patients in 26 primary care health centers in Spain.[39] In this study, text messages were sent only twice per week, which was the lowest frequency among the studies that evaluated text messaging interventions. Three other studies examined HF patients' use of telemonitoring via mobile phones with primary endpoints of death and hospitalization-related outcomes.[30,33,35] In one of these studies, 710 HF patients were followed for 24 months,[30] while the other two studies followed patients for 6 months (N=94, N=120).[33,35] User experience was examined by Vuorinen et al. and feedback from HF patients and health care providers was excellent.[35] The fourth null study involved the use of a mobile app and monitoring device in stroke patients in South Korea.[42] Patients only used the mobile app 60 out of 180 days and secondary outcomes (BP, HbA1c, target waist circumference, smoking rate, drug adherence, exercise) did not differ between those who were and were not compliant with the mobile app.[42] The last study compared HTN self-care behaviors (medication adherence, PA, diet) and BP response between four groups: (a) self-care education over eight 1-hour sessions, (b) self-care education through four pamphlets, (c) self-care education through eight SMS, and (d) usual care.[36] The text messaging group did not have any changes in self-care behaviors;

however, only eight SMS were delivered over 8 weeks compared to eight 1-hour face-to-face sessions.[36]

Several meaningful patterns were observed for both the positive and negative studies using text messaging (Table 2). Factors associated with positive outcomes tended to have at least one of the following characteristics: (a) higher frequency of text messages; (b) personalized text message content with tailored advice; (c) 2-way SMS (request for a text message response from the participant); (d) timing frequencies correlated to medication prescriptions; (e) higher frequency of text messages; (f) greater engagement by the user; and (g) use of multiple modalities (i.e. SMS, mobile app). The majority of text messaging studies used personalized text message content such as participants' names, medication name and/or dosage, catered timing based on the individual's prescription, individualized message copy related to the participant's condition, motivational text correlating to the participant's indicated goals, and content matching the participant's individual barriers (i.e. forgetfulness vs. fear of side effects of medications). Most text messaging studies requested participants to respond with text messages or enter data into supporting software; and all of these studies found positive adherence or clinical outcomes. These patterns suggest the importance of high frequency, interactive mHealth models using individualized, personalized messaging.

A variety of research designs and methodologies were used to conduct the various studies. There were 19 randomized clinical trials, one randomized cluster study, one prospective clinical trial, five feasibility/pilot studies, and two observational studies. Methods for retrieving participant clinical outcomes data varied from self-report (electronic, telephone, questionnaires, interviews), telemonitoring, tracking devices (i.e. in-home ECG electrodes, BP monitors, accelerometers, glucometers), and biomarkers (i.e. exercise workload, blood pressure, laboratory tests). Sample sizes ranged from 6 to 710 participants. Fifteen out of 28 studies (54%) had sample sizes of 100 participants or fewer. The mean age range of participants was between 49 and 66.7 years in all the studies.

Six studies used a mobile app in their intervention; while six additional studies used smartphones for telemonitoring. Three of the studies using mobile apps were observational;[28,29,42] while the other three were randomized studies.[23,27,35] Two of these randomized studies combined mobile apps with other interventions, such as text messaging and telephone coaching.[23,27] One of these studies combined both a mobile app for tracking step counts and text messaging.[23] The study found that mobile app step tracking alone did not increase step counts, but when automated text messages were added, step counts significantly increased.[23]

Discussion

Our review of 28 mobile phone studies found that an overwhelming majority of studies were efficacious in improving behaviors and clinical outcomes in older patients with CVD. The majority of studies used text messaging as the intervention while fewer studies used smartphone technology in the form of mobile apps and telemonitoring. A quarter of the studies used multiple modalities, which may be a growing trend in intervention studies. This review represents a variety of CV conditions with the majority addressing CHD as the primary condition. While medication adherence was the most commonly measured primary outcome, only five studies measured major clinical endpoints (i.e. death, hospitalization, and emergency department visits), and none found any effect on these outcomes. [28,30,33–35] Our findings are consistent with other reviews that reported overall positive potential for mHealth technology to improve various behaviors and clinical outcomes in different populations.[17,46–50] Compared to others, our paper provided an updated search of focused text messaging and mobile apps interventions with clinical outcomes related to the secondary prevention of CVD. In addition, our study confirms that despite the study population of CVD patients being older, a strong majority of the studies had positive clinical outcomes and patient satisfaction.

All studies using text messaging or mobile apps compared with another technology intervention (i.e. Internet or continuous monitoring) found both user adherence and satisfaction to be highest in the text messaging or mobile app intervention groups. One positive adherence study using an intervention of daily text messages in combination with a supporting website found that the majority of participants (85%) reported reading their text messages while the median number of visits to the website was only 3 visits in a 6 month period. [25] This suggests mHealth interventions such as text messaging may have a higher likelihood of patient participation and adherence than Internet-based programs. The majority of studies that used text messaging as a primary intervention for medication or behavior adherence reminders sent SMS messages at least once daily. The two null studies using text messaging had a very low frequency of SMS delivery (i.e. once or twice weekly).[36,39] These findings support that, when text message reminders are used as an intervention to enhance adherence, a frequency of at least once daily should be considered.

Early evidence on the use of mobile apps for CVD management suggests that there is tremendous potential for mobile apps to enhance CVD secondary prevention and self-care. Important lessons emerged from two RCTs employing mobile apps. Martin et al. demonstrated that a mobile app for tracking physical activity alone was not sufficient for improving outcomes, but when the mobile app was combined with text messaging, there was a significant increase in PA.[23] This suggests that the use of mobile apps for tracking may need to be combined with other intervention components. Furthermore, Varnfield et al. showed that using a mobile app as part of a home CR program increased uptake, adherence, and completion rates compared to traditional center-based CR, while producing similar improvements in exercise capacity.[27] This suggests that mobile apps have the potential to extend effective CVD secondary prevention programs to more people (i.e. difficulty with access to health programs, living in rural areas) and promote long-term engagement. However, many questions remain about the impact of mobile apps on health outcomes in larger populations, whether mobile apps will have long-term efficacy, and how to integrate the use of mobile apps into the health care system.

Accurate measurement of both participant adherence and biomarkers are crucial in establishing mHealth as a meaningful tool for improving CV health. Linking mobile phones with the wireless capability of sensors and trackers will continue to influence whether patients sense a burden in monitoring their health. Currently, one in ten mobile apps have the capability to connect to a device or sensor to improve the accuracy and convenience of data collection.[13] The real-time communication of mobile technologies and devices will serve as a potential catalyst for the development of instant feedback to patients about potentially critical medical conditions (i.e. volume overload, arrhythmia, hypertensive crisis). Mobile health may bridge the gap between advancements in CVD patient surveillance through monitoring devices while importantly offering an additional support system for patients managing CVD.

This review of 28 studies highlights substantial variation in the quality of research to support mobile phones for CVD prevention and management, thereby calling for increased rigor in this field of research in numerous ways. First, future research should apply rigorous study designs and research methodologies that have accurate sample size calculations based on realistic effect sizes, careful measurement, and appropriate statistical analyses to move the science of mHealth forward.[48] Second, longitudinal studies will help determine the efficacy and sustainability of these interventions to engage individuals with chronic disease. The longest study period was 24 months, with the mean study duration being approximately 5 months. Since testing interventions in research settings for a short period of time is significantly different from long-term implementation, principles of implementation science must be carefully considered for mHealth interventions to succeed. Third, major clinical outcomes such as rehospitalization and mortality will be important outcomes to follow in large, multi-site studies in various populations. In our review, we found 5 studies that reported major clinical outcomes. Fourth, future research should include cost-effectiveness trials to determine the benefits of promoting mHealth interventions to health care systems and insurance providers for wider dissemination. Cost-effectiveness studies will be important since CVD and disability is now affecting people younger than the age of 70 years in lower/middle-income countries.[51,52] In addition, health care utilization should be considered. Vuorinen et al. reported that the experimental group of HF patients participating in home telemonitoring used significantly more health care resources compared to the control group.[35] Fifth, only 7 studies applied theory to support the development, testing, or implementation of the intervention. These theories included Health Belief Model,[41] Social Cognitive Theory,[22,25,44] Self-Efficacy Theory,[24] general behavioral change theory,[28] or a combination of multiple behavioral change theories.[18] Lastly, additional use of qualitative research methods will inform the design, implementation, and adherence of mHealth interventions that can be used on a long-term basis for chronic disease management. During our search, we found only one qualitative research study evaluating a text messaging support system for improving adherence for blood pressure lowering in South Africa.[53]

Several limitations may apply in this review. First, various types of CVD are represented in this review; therefore, we had six conditions represented, which did not account for the special needs of each chronic disease (i.e. stroke vs. HF). Second, we did not conduct a quantitative meta-analysis of the results as the type and quality of the studies varied substantially. Although the data were too heterogeneous to conduct meta-analyses; we used a narrative synthesis to establish the potential of mHealth to promote CVD self-management. Third, many studies combined the use of multiple technologies which made it difficult to tease out the unique contribution of the individual intervention components (i.e. text messaging, mobile app, telemonitoring via smartphone).

Future mHealth interventions will likely use a combination of different technologies: basic cellular phone, smartphones, computers, and tablets.[54] With the proliferation of smartphones, mHealth apps will likely expand on their connectivity with social media to maximize consumer engagement as 65% of the top mHealth apps currently connect to this popular source of communication.[13] Concerns of privacy and security issues will need to be addressed with the use of social media and in patient-provider communication portals. With hundreds of mHealth clinical trials underway, we will continue to build the evidence of mobile phone interventions to improve behavioral and clinical outcomes.[13]

Conclusions

These findings demonstrate the strong potential for mobile phone features such as text messaging and mobile apps to positively impact the secondary prevention of CVD. Despite the variability in the quality of the included studies, it is promising that the overwhelming majority of the studies showed positive results in a study population of older patients with CVD. However, it remains difficult to draw conclusions on the effectiveness of these interventions for long-term use and improving major clinical endpoints such as death and hospitalizations.

Mobile health provides an exciting opportunity to improve chronic disease management because mobile phones are so commonly used, widely accepted, easily accessible, and affordable. Future research will need to apply rigorous research designs with theory-based interventions that consider the rapidly evolving nature of mHealth technology. Although the use of mobile technology may be novel and appealing, incorporating principles of behavioral activation will help promote and sustain healthy lifestyle behaviors in patients with CVD that result in improved clinical outcomes.

Abbreviations and Acronyms

App	application
BP	blood pressure
CHD	coronary heart disease
CR	cardiac rehabilitation
CV	cardiovascular
CVD	cardiovascular disease
HF	heart failure
HTN	hypertension
mHealth	mobile health
PA	physical activity
PAD	peripheral artery disease

RCT	randomized controlled trial
SMS	short-messaging service
VHD	valvular heart disease

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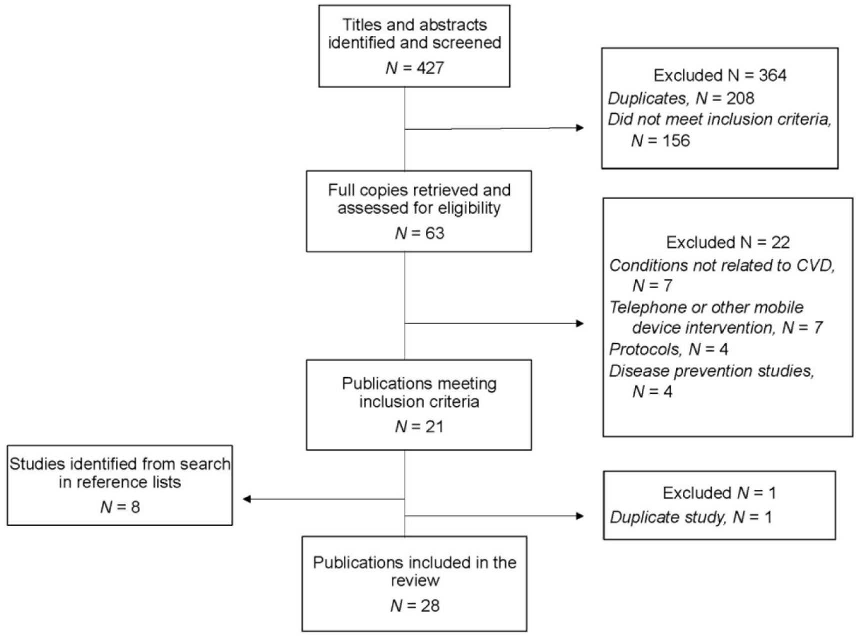
Titles and abstracts identified and screened
N = 427
Excluded N = 364
Duplicates, N = 208
Did not meet inclusion criteria, N = 156
Full copies retrieved and assessed for eligibility
N = 63
Excluded N = 22
Conditions not related to CVD, N = 7
Telephone or other mobile device intervention, N = 7
Protocols, N = 4
Disease prevention studies, N = 4
Publications meeting inclusion criteria
N = 21
Studies identified from search in reference lists
N = 8
Excluded N = 1
Duplicate study, N = 1
Publications included in the review
N = 28

Figure 1.

Table 1

Mobile Phone Studies for the Secondary Prevention of Cardiovascular Disease

First Author, Year, & Country	CV Condition & Outcome	Mobile Health Modality, Design, Sample Size, & Age	Exposure of Experimental and Control Groups & Duration	Results
Antypas 2014 Norway	**CHD;** Physical activity	**SMS, email, website;** RCT; N=69; mean age 59	**Experimental:** SMS and email messages to complete intervention tasks on a website with tailored content + cardiac rehabilitation. **Control:** Access to a non-tailored website + cardiac rehabilitation. **Duration:** 3 months	At 1 month, there was no significant difference in overall physical activity. At 3 months, overall physical activity was higher in the experimental group than in control (5613 vs. 1356 MET-minutes/week; p=0.02).
Blasco 2012 Spain	**CHD;** Resting heart rate, BP, BMI, smoking, LDL-c, and hemoglobin A1c	**SMS, website;** RCT; N=203; mean age 61	**Experimental:** Participants submitted measurements via mobile phone questionnaires. Measurements were reviewed by cardiologists through a web-based interface. Recommendations were sent to participants via SMS. **Control:** Lifestyle counseling. **Duration:** 12 months	The experimental group was more likely than control to improve overall CV risk factor profile (70% vs. 51%; p=0.01). The experimental group was more likely to achieve treatment goals for BP and hemoglobin A1c, but not smoking cessation or LDL-c. BMI was lower in the experimental group.
Chow 2015 Australia	**CHD;** LDL-c, BP, BMI, physical activity, smoking	**SMS;** RCT; N=710; mean age 58 ± 9.2	**Experimental:** 4 SMS per week + usual care. Messages provided advice, motivational reminders, and support to change lifestyle behaviors. **Control:** Usual care. **Duration:** 6 months	At 6 months, LDL-c was lower in the experimental group than control (79 vs. 84 mg/dL; p=0.04). Systolic BP, BMI, physical activity, and smoking were significantly better in the experimental group.
Frederix 2015 Belgium	**CHD;** VO2, physical activity, quality of life	**SMS, email;** RCT; N=140; mean age 61	**Experimental:** Email and SMS coaching + conventional cardiac rehabilitation. **Control:** Conventional cardiac rehabilitation. **Duration:** 24 weeks	At 24 weeks, peak VO2 was higher in the experimental group than in control (24 vs. 22; p <0.001). Self-reported moderate-vigorous physical activity was higher in the experimental group than control (1371 vs. 627 median MET-minutes/week; p=0.01). Health-related quality of life significantly improved in the experimental group vs. control. No significant differences

First Author, Year, & Country	CV Condition & Outcome	Mobile Health Modality, Design, Sample Size, & Age	Exposure of Experimental and Control Groups & Duration	Results
				were observed in weight, BP, hemoglobin A1c, or LDL-c.
Golshahi 2015 Iran	**Hypertension;** Self-care behaviors (medication adherence, physical activity, diet) and BP	**SMS;** RCT; N=180; mean age 56.8 ± 8.9	**Experimental (3 groups):** Group A – self-care education over 8 one-hour sessions; Group B – self-care education through 4 pamphlets; Group C – self-care education through 8 SMS. **Control:** Group D – usual care. **Duration:** 6 months	Face to face self-care training offered BP improvement over pamphlet, SMS, and usual care. No significant changes in all self-care behaviors as well as BP with use of SMS.
Kamal 2015 Pakistan	**CVA;** Medication adherence, BP	**SMS;** RCT; N=200; mean age: Experimental 56 ± 1.5, Control 57.6 ± 1.3	**Experimental:** Reminder SMS messages with personalized medication reminders and twice weekly health information + usual care. **Control:** Usual care. **Duration:** 2 months	Medication adherence was better in the experimental group than in control (mean 7.4 vs. 6.7; p<0.01). There was no significant difference in BP.
Khonsari 2014 Malaysia	**Acute coronary syndrome;** Medication adherence, hospitalization readmission rate, death rate	**SMS;** RCT; N=62; mean age 57.9 ± 12.64	**Experimental:** Automated SMS reminders + usual care. **Control:** Usual care. **Duration:** 8 weeks	In the experimental group, 65% had high adherence compared to 13% in the control group (p<0.001). Functional status was better in the experimental group than control (84% asymptomatic and without limitations vs. 32%; p<0.001).
Kiselev 2012 Russia	**Hypertension;** BP, number of smoked cigarettes, BMI	**SMS;** RCT; N=199; mean age: Experimental 49, Control 51	**Experimental:** SMS reminders from providers and messaging of BP, weight, and cigarette entries from patients. **Control:** Traditional ambulatory care. **Duration:** 1 year	BP goals were achieved in 77% of experimental group patients and 12% of control (p<0.05). There were no significant differences in BMI or smoking.
Logan 2007 Canada	**Hypertension & Type 2 diabetes;** BP	**Telemonitoring using mobile phones;** Pilot study; N = 31; mean age 58.1 ± 9.9	**Experimental:** Mobile phone connected to Bluetooth- enabled BP monitor which transmits readings to database and physician. Patient interface on phone for viewing readings. Automated reminder and feedback messages to patients. **Control:** None. **Duration:** 4 months	Average BP fell by 11/5 mmHg (p<0.001).

First Author, Year, & Country	CV Condition & Outcome	Mobile Health Modality, Design, Sample Size, & Age	Exposure of Experimental and Control Groups & Duration	Results
Maddison 2015 New Zealand	**CHD;** Exercise capacity, physical activity	**SMS, website videos;** RCT; N=171; mean age 60.2 ± 9.3	**Experimental:** SMS messages, website, videos. **Control:** Usual care. **Duration:** 24 weeks	There was no significant difference in exercise capacity. Leisure time physical activity was greater in the experimental group (383 vs. 273 min/week; p=0.04). Walking was greater in the experimental group (512 vs. 361 min/week; p=0.02). The experimental group also had significant improvements in self-efficacy and general health.
Marquez Contreras 2004 Spain	**Hypertension;** Medication adherence	**SMS;** Randomized cluster study; N=104; mean age: Experimental 56.26 ± 10.22, Control 59.43 ± 10.94	**Experimental:** Received SMS 2 days per week. **Control:** Usual care. **Duration:** 6 months	Hypertension was controlled in 64.7% (95% CI 48.6–80.8%) of experimental patients and 51.5% (95% CI 34.4–68.6%) of control patients (p>0.05).
Martin 2015 USA	**CHD and/or diabetes;** Physical activity	**Mobile app & SMS;** RCT; N=48; mean age 58 ± 8	**Experimental (2 groups):** 1) unblinded smartphone step tracking for 4 weeks; 2) unblinded smartphone step tracking for 2 weeks with the addition of automated coaching SMSs for the final 2 weeks. **Control:** Blinded tracking. **Duration:** 2 weeks	Baseline activity was 9670 steps/day. Tracking alone did not result in significantly higher step counts. Participants receiving SMS increased their step counts by 2534 compared to tracking participants not receiving SMS and 3376 compared to blinded controls (p<0.001 for both).
Nundy 2013 USA	**Heart failure;** HF self-care	**SMS;** Pilot study - pre/post design; N=15; mean age 50	**Experimental:** SMS on medication / dietary / appointment adherence, HF signs and symptoms recognition / management, health care navigation. **Control:** N/A. **Duration:** 4 weeks	Self-care maintenance (mean composite score 49 to 78, p=0.003) and self-care management (57 to 86, p=0.002) improved at 4 weeks, whereas self-care confidence did not change (57 to 75, p=0.11).
Park 2014 USA	**CHD;** Medication adherence	**SMS;** RCT; N=90; mean age: Experimental 58.2 ± 10.6, Control 61.1 ± 9.1	**Experimental (2 groups):** 1) SMS for medication reminders and education; 2) SMS for education only. **Control:** No SMS. **Duration:** 30 days	Electronic monitoring confirmed antiplatelet doses taken were 93.7% for SMS for medication reminders and education, 95.8% for SMS for education, and 79.1% for no SMS (p=0.03). There was no significant difference in statin adherence. There were no significant differences

First Author, Year, & Country	CV Condition & Outcome	Mobile Health Modality, Design, Sample Size, & Age	Exposure of Experimental and Control Groups & Duration	Results
				in patient- reported adherence.
Pfaeffli Dale 2014 New Zealand	**CVD;** Usability and acceptability of a healthy eating program & self-efficacy	**SMS, website;** Pilot study - pre/ post design; N=20; mean age 52 ± 15.5	**Experimental:** 1) SMS on healthy dietary changes and increases in self-efficacy, 2) role model vignettes and educational internet support. **Control:** N/A. **Duration:** 4 weeks	Participants read all/ most of the SMSs and 19/20 with high satisfaction. The website was not widely used - reported to be time consuming. Heart healthy eating self-efficacy increased, in particular the environmental self-efficacy subset (mean=0.62 ± 0.74, p=0.001).
Pfaeffli Dale 2015 New Zealand	**CHD;** Health behaviors, medication adherence	**SMS;** RCT; N=123; mean age 59.5 ± 11.1	**Experimental:** mHealth program with daily SMS messages and supporting website. **Control:** Usual care. **Duration:** 24 weeks	Adherence to healthy lifestyle behaviors was greater in the experimental group at 3 months (AOR 2.55, 95% CI 1.12 to 5.84), but not at 6 months (AOR 1.93, 95% CI 0.83 to 4.53). Self-reported medication adherence at 6 months was greater in the experimental group than control (7.3 vs. 6.8; p=0.004).
Piotrowicz 2012 Poland	**Heart failure;** ECG recordings during home-based telemonitored cardiac rehabilitation	**Telemonitoring using mobile phones;** Feasibility study; N=77; mean age 64	**Experimental:** Participated in home-based telemonitored cardiac rehabilitation. Patients answered questions about fatigue, dyspnea, BP, weight, and medications through the mobile phone. ECG fragments were recorded and transmitted via mobile phone to a monitoring center. **Control:** N/A. **Duration:** 8 weeks	During the study, 11,534 transmitted ECG fragments were evaluated. HF patients undergoing home-based telemonitored cardiac rehabilitation did not develop any arrhythmia which required a change of the procedure, confirming it was safe.
Quilici 2013 France	**CHD;** Medication adherence	**SMS;** RCT; N=521; mean age 64	**Experimental:** SMS messages about aspirin adherence. **Control:** Usual care. **Duration:** 1 month	Platelet aggregation testing confirmed medication nonadherence was better in the experimental group than control (5.2% vs. 11.2%; p=0.01).
Scherr 2009 Austria	**Heart failure;** Death, hospitalization	**Telemonitoring using mobile phones;** RCT; N=120; median age 66	**Experimental:** Patients were equipped with mobile phone-based patient terminals for health data acquisition and data transmission to the	There was a non-significant difference in death or hospitalization for HF in the experimental group than in control (17% vs. 33%, p=0.06). 12/54

First Author, Year, & Country	CV Condition & Outcome	Mobile Health Modality, Design, Sample Size, & Age	Exposure of Experimental and Control Groups & Duration	Results
			monitoring center + usual care. **Control:** Usual care. **Duration:** 6 months	experimental participants were never able to begin data transmission.
Seo 2015 Korea	**CVA;** Primary: days of mobile app use. Secondary outcomes: BP, HbA1c, target waist circumference, smoking rate, drug adherence, exercise.	**Mobile app and monitoring device;** Prospective clinical trial; N=48; mean age 52.7 ± 10.3	A single-arm group was given a mobile app for daily acquisition of vascular risk factor parameters. This group was then divided into 2 groups: **Experimental:** Compliant mobile app users. **Control:** Noncompliant mobile app users. **Duration:** 6 months	The number of days patients entered data into the mobile app was 60.42 ± 50.17 (median, 47 days; range, 1–180 days). The secondary outcomes did not differ between the compliant and noncompliant groups.
Seto 2012 Canada	**Heart failure;** Primary: BNP, self care, and quality of life. Secondary: LVEF, NYHA class, medications, hospital readmissions, ED visits, mortality	**Telemonitoring using mobile phones;** RCT; N=100; mean age: Experimental 55.1 ± 13.7, Control 52.3 ± 13.7	**Experimental:** Telemonitoring for daily weight and BP as well as weekly single-lead ECGs if they did not have a defibrillator. Answered daily symptom questions on a mobile phone + standard of care. **Control:** Standard of care (HF education, care at HF clinic). **Duration:** 6 months	Quality of life ($p=0.05$) and self-care maintenance ($p=0.03$) were signicantly greater for the experimental group compared to the control group. In a sub-group analysis of those who attended the clinic for more than 6 months, the experimental group had signicant improvements in BNP ($p=0.02$), LVEF ($p=.005$), self-care maintenance ($p=0.05$) and management ($p=0.03$), while the control group did not.
Stuckey 2011 Canada	**Metabolic syndrome risk;** Weight loss, improvement in biomarkers for metabolic syndrome, exercise	**Telemonitoring using mobile phones;** Feasiblity study; N=24; mean 56.6 ± 8.9	**Experimental:** Mobile app transmittted BP and glucose and allowed manual entry of step counts and weight. A care team viewed measurements and provided counseling. **Control:** None. **Duration:** 8 weeks	Participants had significant improvements in BMI, diastolic BP, exercise capacity, and self-reported step counts. There were no significant differences in glucose or LDL-c.
Varnfield 2014 Australia	**CHD;** Uptake, adherence and completion of a cardiac rehabilitation program	**Mobile app, SMS, video/ audio files, web portal;** RCT; N=120; mean age 56	**Experimental:** Mobile app + weekly telephone mentoring. **Control:** Traditional center-based cardiac rehabilitation. **Duration:** 6 weeks	Experimental group had higher uptake (80% vs. 62%), adherence (94% vs. 68%) and completion (80% vs. 47%) rates than control ($p<0.05$). There was no significant difference in exercise capacity in experimental and control groups at 6 weeks (570 vs 584m on six-minute walk test). Health-related

First Author, Year, & Country	CV Condition & Outcome	Mobile Health Modality, Design, Sample Size, & Age	Exposure of Experimental and Control Groups & Duration	Results
				quality of life was better in the experimental group than in control (p=0.01).
Vuorinen 2014 Finland	**Heart failure;** Primary: HF-related hospital days. Secondary: clinical status, use of health care resources, and user experience.	**Mobile app, telemonitoring devices;** RCT; N=94; mean age: Experimental 58.3 ± 11.6, Control 57.9 ± 11.9	**Experimental:** Mobile app to report weight, BP, pulse, and symptom-related questions on a weekly basis. **Control:** Usual care. **Duration:** 6 months	No difference in the number of HF-related hospital days (IRR=0.81, p=0.35). The intervention group used more health care resources (p<.001). No significant differences in patients' clinical health status or in their self-care behavior.
Wald 2014 London	**Hypertension;** Medication adherence	**SMS;** RCT; N=303; mean age: Experimental 60 ± 7, Control 61 ± 10	**Experimental:** Sent daily SMS for 2 weeks, alternate days for 2 weeks and weekly thereafter. **Control:** No SMS. **Duration:** 6 months	Taking less than 80% of the prescribed regimen occurred less frequently in the experimental group compared to control (9% vs. 25%, p<0.001).
Widmer 2015 USA	**CHD;** Weight, BP, lipids, exercise capacity, rehospitalization, ED visits	**Mobile app;** Observational; N=42; mean age 66.7	**Experimental:** Mobile app prior to or after 3 months of traditional cardiac rehabilitation. **Control:** Traditional cardiac rehabilitation. **Duration:** 3 months	Experimental group participants had significant improvements in systolic BP, weight, lipids, and exercise capacity. Rehospitalizations and ED visits were lower in patients using a mobile app during cardiac rehabilitation (20% in users vs. 58% in non-users, p=0.01) and after 3 months of cardiac rehabilitation (28% lower; p=0.04).
Worringham 2011 Australia	**CHD;** Exercise capacity	**Mobile app;** Observational; N=6; mean age 53.6	**Experimental:** Mobile app with ECG monitoring, telephone contact pre/post exercise. **Control:** None. **Duration:** 6 weeks	Exercise capacity improved from 524 to 637 m on six-minute walk test (p=0.009).

Abbreviations: AOR-adjusted odds ratio; app-application; BMI-body mass index; BNP-brain nauretic peptide; BP-blood pressure; CHD-coronary heart disease; CI-confidence interval; CV-cardiovascular; CVA-cerebrovascular accident; ECG-electrocardiogram; ED-emergency department; HF-heart failure; IRR-incidence ratio rate; LDL-c-low density lipoprotein cholesterol; LVEF-left ventricular ejection fraction; MET-metabolic equivalent; NYHA-New York Heart Association; RCT-randomized controlled trial; SMS-short messaging service (text messages); VO2-maximum volume of oxygen.

Table 2

Factors Associated with Positive Outcomes

Higher frequency of text messages
Personalized text message content with tailored advice
Two-way SMS
Timing frequencies correlated to medication prescriptions
Higher frequency of text messages
Greater engagement by the user
Use of multiple modalities (i.e. SMS, mobile app)