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Using Mobile Health (mHealth) Technology in the Management of Diabetes Mellitus, Physical Inactivity, and Smoking

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Abstract
Purpose of Review Cardiovascular mortality remains high due to insufficient progress made in managing cardiovascular risk factors such as diabetes mellitus, physical inactivity, and smoking. Healthy lifestyle choices play an important role in the management of these modifiable risk factors. Mobile health or mHealth is defined as the use of mobile computing and communication technologies (i.e., mobile phones, wearable sensors) for the delivery of health services and health-related information. In this review, we examine some recent studies that utilized mHealth tools to improve management of these risk factors, with examples from developing countries where available.

Recent Findings The mHealth intervention used depends on the availability of resources. While developing countries are often restricted to text messages, more resourceful settings are shifting towards mobile phone applications and wearable technology. Diabetes mellitus has been extensively studied in different settings, and results have been encouraging. Tools utilized to increase physical activity are expensive, and studies have been limited to resource-abundant areas and have shown mixed results. Smoking cessation has had promising initial results with the use of technology, but mHealth's ability to recruit participants beyond those actively seeking to quit has not been established.

Summary mHealth interventions appear to be a potential tool in improving control of cardiovascular risk factors that rely on individuals making healthy lifestyle choices. Data related to clinical impact, if any, of commercially available tools is lacking. More studies are needed to assess interventions that target multiple cardiovascular risk factors and their impact on hard cardiovascular outcomes.

Keywords mHealth · Mobile health · Cardiovascular diseases · Smoking cessation · Diabetes mellitus · Physical inactivity

This article is part of the Topical Collection on *Coronary Heart Disease*

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Introduction

Atherosclerotic cardiovascular diseases (ASCVDs) account for an estimated 17.3 million deaths annually, 610,000 of which occur in the USA alone [1, 2]. While improved management of cardiovascular disease risk factors such as hypertension and hyperlipidemia has improved cardiovascular outcomes, mortality related to cardiovascular diseases remains high due to insufficient progress in managing other modifiable risk factors—especially those related to lifestyle—such as diabetes mellitus, physical inactivity, and smoking [3].

Management of the risk factors mentioned above requires lifestyle modification as pharmacotherapy alone is rarely sufficient. It is, therefore, not surprising that poor lifestyle choices and behaviors were cited as the foremost reasons behind the disease burden related to ASCVD in the American Heart Association Heart Disease and Stroke Statistics report [3]. While counseling from healthcare providers plays an important role in educating patients regarding these lifestyle changes, the frequency and duration of these interactions are often not enough. Other modalities, such as support groups and group sessions, have shown some promise but have similar limitations. Technology—now an integral part of everyday life—is considered a potential solution in the form of mobile health.

mHealth

Mobile health or mHealth is defined as the use of mobile computing and communication technologies (i.e., mobile phones, wearable sensors) for the delivery of health services and health-related information [4]. Modalities utilized in mHealth include text messaging, video messaging, Web sites, and more recently, mobile phone applications. These may be used to provide immediate access to healthcare resources, record or transmit clinical data, or communicate with healthcare providers. Its economic feasibility and round-the-clock availability makes it a potentially viable option in a wide variety of settings. This was best reflected in a 2009 World Health Organization (WHO) survey that showed 83% of 112 participating member countries to have at least one mHealth intervention in place [5].

Various mHealth modalities have been tested to improve outcomes related to the control of cardiovascular disease risk factors including diabetes mellitus, physical inactivity, and smoking. In this review, we describe and summarize some of the more recent studies designed specifically for the abovementioned risk factors, with examples from developing countries where available. Given the sheer number of publications in this area, this review is not meant to be exhaustive. The role of mHealth in the management of hypertension and hyperlipidemia, two other modifiable cardiovascular risk factors, is covered in another review.

Diabetes Mellitus (Table 1)

Poor control of diabetes mellitus is associated with coronary artery disease, peripheral vascular disease, and cardiomyopathy [6]. Its management consists of a combination of pharmacotherapy and lifestyle modifications. Hence, most mHealth interventions for diabetes focus on medication adherence and healthy lifestyle choices.

In our search, we came across one study from Pakistan in which calling patients on their cell phones was the only intervention [7]. Participants in the intervention group received a phone call every 15 days for 4 months. The purpose of these phone calls was to remind patients to self-monitor blood glucose levels, encourage them to take their medications on time, and be physically active. The control group received usual outpatient clinic visits. At 4 months, HbA1c decreased from 10.09 to 8.63% in the intervention group and from 9.85 to 9.36% in the control group ($p < 0.001$).

Among studies that used short messaging service (SMS) as the intervention, the major difference was the content of SMS. One study used SMS to educate their 100 participants regarding diabetes [8]. HbA1c decreased from 9.9 to 9.5% among participants ($p = 0.014$). However, there was no control group for comparison. Goodarzi et al. used a similar approach in which the SMS content included recommendations related to diabetes knowledge, attitude, practice, and self-efficacy [9]. The control group received usual care. Results from the study suggested no significant change in HbA1C between the two groups (0.89% in the intervention group vs 0.35% in the control group, $p = 0.24$). In contrast, content for text messages in the Text-MED study, conducted on 128 participants, was developed from the National Diabetes Education Program and expert endocrinology opinion. Patient knowledge gaps were identified through prior experiences and pilot work [10]. Text messages sent to the participants in the intervention group included motivational and educational texts, medication reminders, easily attainable healthy living challenges (for example, avoiding soda for a day), and diabetes-related trivia. The control group received usual care. At 6 months, HbA1c levels showed a decrease from 10.1 to 9.05% in the intervention arm and from 9.85 to 9.25% in the control arm ($p = 0.23$). SMS content for another study in Bangladesh was based on the principles of behavioral learning theory [11]. According to this theory, human response and behaviors are learned through association, consequences, and observation. The study reported significantly improved diabetes control in the intervention group as compared to the control group not receiving any intervention (assessed by least squared mean difference of −0.66 between the two groups, $p < 0.00001$). Mulvaney et al. asked patients to identify barriers to their diabetes care which was then used to tailor the SMS content for participants in the intervention group [12]. Although the HbA1c levels in the intervention group remained unchanged from baseline (8.8%), they did increase from 8.9 to 9.9% in the control group ($p = 0.006$). Another intervention in the MED study also identified patient barriers prior to tailoring the content delivered to patients, but it combined the use of daily SMS consisting of reminders and counseling with weekly phone calls [13]. Patients were requested to respond to whether or not they had taken the medications through SMS. The interviews served to provide aggregated feedback for the week.

Table 1 Summary of mHealth-related studies for diabetes mellitus management

Study cited, year of publication, country duration	Sample size	Technology used	Intervention	Results
Shahid et al. [7] (2014) Pakistan 4 months	$n = 440$ Int: 220 Cont: 220	Phone	Int: called on cellphone every 15 days for 4 months (8 in total) Cont: usual care	Change in HbA1c: Int: −1.46 Cont: −0.48 (p value < 0.0001)
Abbass et al. [8] 2014 Saudi Arabia 4 months	$n = 100$ Int: 100 Cont: No control group	SMS	Int: Five to seven SMS sent weekly regarding general diabetes care Cont: No control group	Mean decrease in Hb A1C Int: −0.4% (9.9 to 9.5%) ($p = 0.014$)
Goodarzi et al. [9] 2012 Iran 12 weeks	$n = 81$ Int: 43 Cont: 38	SMS	Int: 4 messages weekly consisting of information about exercise, diet, diabetic medication, importance of self- monitoring blood glucose levels Cont: Usual care	Change in HbA1c Int: −0.89% Cont: −0.35% ($p = 0.24$)
TExT-Med [10] 2014 USA 6 months	$n = 128$ Int: 64 Cont = 64	SMS	Int: 2 SMS daily relating to education, medication reminders, healthy living challenges and diabetes trivia Cont group: Usual care	Mean decrease in Hb A1C Int: 1.3% (10.10 to 9.05%) Cont: 0.90% (9.85 to 9.25%) ($p = 0.23$)
Islam et al. [11] 2015 Bangladesh 6 month	$n = 200$ Int: 106 Cont: 94	SMS	Int: 90 SMSs once daily for 6 months to increase medication compliance Cont: Usual care	Least squares mean difference of HbA1c Int: 20.85 Cont: 20.18 ($p < 0.0001$)
Mulvaney et al. [12] 2012 USA 3 months	$n = 46$ Int: 23 Cont: 23	SMS	Int: 10 text messages per week at an average addressing barriers of diabetes care Cont: Usual care	Change in HbA1c: Int: No change Cont: +1.0% ($p = 0.006$)
MED [13] 2016 USA 3 months	$n = 240$ Int: 160 Cont: 80	SMS Interview	Int: Tailored daily SMS addressing diabetes care barriers and assessing if patient had taken medications and weekly IVR call Cont: Usual care	HbA1c Int: 8.3 to 8.0% Cont: 8.3 to 8.0%
Tamban et al. [14] 2013 USA 6 months	$n = 104$ Int: 52 Cont:52	SMS	Int: 3 SMS per week about diet, exercise and consequences of not adhering to DM management Cont: Usual care	Change in HbA1c: Int: −0.82% Cont: −0.52% ($p = 0.04$)
Yarahmadi et al. [15] 2014 Iran 3 months	$n = 64$ Int: 32 Cont: 32	SMS	Int: Six sessions on diabetes education and its care followed by SMS for 8 weeks Cont: Six sessions of diabetes education only	Change in HbA1c: Int: −0.65% Cont: −0.12% ($p < 0.01$)
SMS-DM [16] 2011 Bahrain 3 months	$n = 34$ Int: 12 Cont: 22	SMS	Int: Provided with the clinician's and the educator's to send unlimited free SMS in between the clinic visits regarding patient needs Cont: Usual care	Change in HbA1c Int: −2.76% Cont: −1.6% ($p = 0.001$)
Bell et al. [17] 2012 USA 12 months	$n = 64$ Int: 31 Cont: 33	Video messages	Int group: Self-care video messages sent daily to cell phones for 9 months Cont group: Usual care	Mean decrease in Hb A1C Int: 1.3% Cont: 0.9%
Dial-Betics [18] 2016 Japan 3 months	$n = 54$ Int: 27 Cont: 27	Pedometer Glucometer Smart phone	Blood glucose and pedometer counts measured at home and sent automatically to server. Voice/text messages detailing meals manually sent to server. Feedback sent to patient's smartphone.	Change in HbA1c Int: −0.4% Cont: +0.1% ($p = 0.015$)
Tele Diab I [19•] 2011 France 6 months	$n = 180$ Int 1: 61 Int 2: 60 Cont: 59	Mobile app Video conferencing	Int group 1: Home use of a smartphone recommending insulin doses Int group 2: Int 1 with short teleconsultations every 2 weeks Cont group: usual quarterly follow-up	Change in HbA1c: Int group 1: −0.5% Int group 2: −0.7% Cont group: +0.2%
Quinn et al. [20] 2011 USA	$n = 163$ Int 1: 23 Int 2: 22	Mobile app SMS	Int 1: Real-time feedback based on diabetes management information (example, blood glucose values, carbohydrate intake, medications) entered by	Change in HbA1c: Int 1: −1.6% Int 2:−1.2

Table 1 (continued)

Study cited, year of publication, country duration	Sample size	Technology used	Intervention	Results
1 year	Int 3: 62 Cont: 56		patients on their smart phones, access to a web portal that supplemented the mobile app through additional diabetes information Int 2: Int arm 1 + physicians were provided access to unanalyzed data Int 3: Int arm1 + physicians were provided access to analyzed data (DSS arm) Cont: Usual care	Int 3: −1.9% Cont: −0.7% ($p < 0.001$)
CARRS [21••] 2016 India, Pakistan 36 months	$n = 1146$ Int: 575 Cont: 571	Decision support electronic health record (DS-EHR) Phone	Int: Phone calls at least once a month by non-physician clinical coordinators to discuss diabetes self-management, adherence to diet and medications, tobacco cessation Cont: Usual care	Change in HbA1c: Int: −1.6% Cont: −1.2% ($p < 0.01$)

Int intervention group, *Cont* control group, *SMS* short messaging service, *HbA1c* hemoglobin A1c, *Mobile app* mobile application, *IVR* interview

This study did not show a difference in the change in the HbA1c levels with HbA1c being 8.3% at baseline in both intervention and control groups and 8.0% at the end of the study in both groups.

Studies by Tamban et al. and Yarahmadi et al. also used SMS, but this was preceded by educational sessions conducted for participants in intervention and control groups [14, 15]. While the participants in the study by Tamban et al. attended a single 15-min education session after their visit to the endocrinologist, participants in the study by Yarahmadi et al. underwent six different sessions. After these sessions, participants in the intervention groups received SMS to reinforce the education received during these sessions. These studies reported similar findings: at 6 months, Tamban et al. reported a significantly greater drop in HbA1c (from 7.81 to 6.99%) in the intervention group compared to the control group (from 7.86 to 7.34%, $p = 0.04$). In the study by Yarahmadi et al., HbA1c levels decreased from 7.39 to 6.75% in the intervention group and from 7.38 to 7.26% in the control group ($p < 0.01$). The SMS-DM study conducted on 34 patients in Bahrain used SMS as a means of continuous interaction with both physician and diabetic educator [16]. The intervention group was provided with two mobile phone numbers—one belonging to a physician and the other to a diabetic educator—for infinite communication between visits. The intervention showed a decrease in HbA1c from 9.66 to 6.91% while the HbA1c decreased from 10.22 to 8.62% in the control group ($p = 0.001$).

We found one study that evaluated the use of video messaging for diabetes management in which the intervention group received daily self-care videos from their diabetes nurse practitioners for a period of 6 months [17]. Content of the videos was borrowed from other self-care topics (for example, healthy eating, being active) outlined by the American Association of Diabetes Educators. At 12 months, the study showed a decrease in HbA1c of 1.3% in the video messaging group and 0.9% in the control group.

With mobile apps now gaining popularity, they have been frequently used in a variety of ways to assist in diabetes management. The DialBetics study from Japan, for example, used glucometers that transmitted data to a DialBetics server via a wireless network [18]. Analyses of glucometer readings were then communicated to patients via a mobile phone app. The app was also used by patients to send data related to their diet and exercise. This study of 54 participants showed a decrease in HbA1c (7.1 to 6.7%) in the intervention group compared with an average *increase* of 0.1% in the non-DialBetics group (7.0 to 7.1%). In comparison, the Tele-Diab I study used a mobile phone application with an algorithm to assist patients in modifying their basal doses of insulin based on blood sugar readings entered in the app [19•]. The other intervention group received bi-weekly teleconsultation while the control group received usual care. The study showed a decrease in HbA1c in the teleconsultation group (9.11 to 8.41%) and the mobile app group (9.19 to 8.69%), but an increase in the control group (9.07 to 9.27%).

Mobile phone apps have also been used for decision support systems. Decision support systems or DSS are mHealth interventions intended to assist healthcare providers or participants in decision making regarding their health using relevant data. One of the earlier studies using mHealth for DSS consisted of four arms, three of which were intervention arms [20]. The first intervention arm received real-time feedback based on diabetes management information (for example, blood glucose values, carbohydrate intake, medications) entered by patients on their smart phones. This group was also given access to a Web portal that supplemented the mobile app with additional information such as historical data and laboratory values. In addition to the interventions in the first intervention arm, physicians were provided access to unanalyzed data in the second intervention arm and analyzed patient data in the third intervention arm (DSS arm). The results suggested a decrease in HbA1c in the control and all three intervention groups with the greatest decrease in the DSS arm. The recently reported CARRS trial conducted in India and Pakistan also tested a DSS intended to guide clinical care by coordinators [21••]. Participants in the intervention group received a minimum of one phone call every 3 months from a non-physician clinical coordinator to discuss diabetes self-management, healthy lifestyle choices, and clinic appointments. Data obtained from these interactions was recorded in the decision-support electronic health record (DS-EHR) which then analyzed it through an algorithm based on clinical guidelines to prompt management options. The final treatment changes laid with the treating physician. The control group received usual care. The study showed a decrease in HbA1c of 1.5% in the intervention group and 1.2% in the control group ($p < 0.001$). The study also measured the effect of the intervention on blood pressure (5.4 mm Hg greater decrease in intervention group, $p < 0.001$), cholesterol (7.1 mg/dL greater decrease in LDL-C in intervention group, $p = 0.005$) and weight (0.09 kg greater decrease in intervention group, $p = 0.79$).

In summary, mHealth interventions do appear to have a role in improving management of diabetes mellitus; however, they often require support from other modalities such as online tools or in-person educational sessions, especially in the case of SMS. Studies involving SMS as the only intervention showed mixed results. Its low cost however still makes it a frequently studied mHealth intervention and the "go to intervention" for developing countries. Mobile phone applications are now starting to gain popularity. Notably, many of these studies provided participants with glucometers and glucose strips. While this was necessary to reduce lack of participation due to limited resources, it also makes these studies less applicable to low resource settings. In some cases, when provided with glucometer and glucose strips, control groups also showed HbA1c reductions, indicating that perhaps the most important intervention needed in diabetes management is adequate access to medications and glucose testing supplies. Long-term studies are required to assess the effectiveness of mHealth technology in the management of a chronic disease like diabetes.

Physical Activity (Table 2)

Despite proven benefits on physical and mental health, physical activity levels in the USA have declined in the last two decades. Lack of motivation and time are often cited as common barriers. The role of mHealth in this regard has been primarily to motivate participants and provide objective targets and measurements through activity monitors (for example, pedometers).

As with diabetes, SMS has been a commonly employed intervention. The interventions differ in terms of the method used to measure physical activity. A recent pilot study of 82 university students measured physical activity through questionnaires [22]. The intervention group received text messages encouraging them to increase their non-sedentary behaviors. The control group received usual care. The sum of physical activity and standing time increased by 81.35 min in the intervention group while it decreased by 27.26 min in the control group. The study, however, was limited by a high proportion of participant dropout (31.7%). A similar study in Malaysia sent text messages derived from effective behavior change techniques encouraging participants to exercise [23]. Physical activity was assessed through interviews. Participants in intervention and control groups were provided exercise reading materials. Although the results at 12 weeks suggested an increased frequency of exercise in the intervention arm, this difference was no longer significant at 24 weeks. Spark et al. also assessed physical activity through interviews as a continuation of a previous telephone intervention [24]. The SMS reminders served to reinforce the prior intervention. This study of 29 participants showed an average increase in daily physical activity of 10.4 min, although it was done without a control group.

More commonly, SMS are combined with other modalities. One of the more commonly used combinations are SMS with Web sites. This approach was used in the HEART mobile phone trial as well as two other studies [25–27]. All three studies were conducted on patients with cardiovascular disease, and their physical activity was assessed by patient-filled questionnaires. The HEART mobile trial provided exercise prescriptions, technical support, and behavior change strategies via SMS. This was supported by access to a Web site that included exercise tips, motivational messages, and physical activity progress. The control group was free to pursue any other form of cardiovascular exercise. The study showed a 426 MET-min/week greater rise in leisure time physical activity ($p = 0.04$) and a 500 MET-min/week greater increase in walking ($p = 0.01$) in the intervention group. The second study followed a 4-week inpatient cardiac rehabilitation program. The control group received an Internet-based intervention consisting of general information about cardiovascular disease and lifestyle modification (for example, diet, physical activity, smoking, and medication) and a discussion forum. Participants in the intervention group received the Internet-based intervention as well as tailored content via a Web site and SMS. Content was tailored based on algorithms that used questionnaire data to determine the participant's intervention path. The median MET-min reported in the study increased by 4738 min in the intervention arm while it decreased by 3234 min in the control group. The TEXT4HEART study was conducted on 123 participants diagnosed with coronary artery disease. In addition to being offered standard cardiac

Table 2 Summary of mHealth-related studies to increase physical activity

Study cited, year of publication, country duration	Sample size	Technology used	Intervention	Results
Cotten et al. [22] (2016) UK 6 weeks	$n = 56$ Int: 26 Cont: 30		Int group: Daily text messages scheduled by the researcher encouraging breaks from sitting, standing, light- and moderate-intensity physical activity (PA) Cont group: Daily text messages in the evenings about random health or nutrition facts	Change in activity Int: Standing +18.25 min/day, LIPA + 50.07 min/day, MIPA + 13.03 min/day (total increase in PA/standing of 81.35 min) Cont group: Standing −6.05 min/day, LIPA −24.27 min/day, MIPA + 3.06 min/day (total net decrease of 27.26 min)
Muller et al. [23] (2016) Malaysia 24 weeks	$n = 21$ Int:18 Cont: 21	SMS	Int : Exercise booklet and 5 weekly SMS text messages over 12 weeks Cont: Exercise booklet only	Change in exercise self-efficacy score Int: −3.02, Cont: −14.32 ($p = 0.18$)
Spark et al. [24] (2015) Australia 6 months	$n = 23$ Int = 23 Cont: No control group	SMS	Int: 6-month tailored text messages Cont group: No cont group	Mean change in physical activity + 10.4 min/day (from 27.3 to 37.7) ($p = 0.003$)
HEART mobile phone trial [25] (2014) New Zealand 24 weeks	$n = 171$ Int: 85 Cont: 86	SMS	Int: Personalized, automated package of text messages over 24 weeks Cont: Any other cardiac services or support that they wished to use	Difference in int and cont Leisure-time physical activity: 426 MET-min/week ($p = 0.04$) Walking: 500 MET-min/week ($P = 0.01$)
Text4Heart [26] (2015) New Zealand 6 months	$n = 123$ Int: 61 Cont: 62	SMS Web site	Int: Personalized SMS and a supporting Web site × 24 weeks Cont: Usual care	Change in percentage of participants physically active Int: +3% (from 28 to 31%) Cont: +13% (from 11 to 24%)
Antypas et al. [27] (2014) Norway 3 months	$n = 18$ Int: 7 Cont: 12	SMS Web site	Int: Access to Web site with information regarding cardiac rehabilitation, an online discussion forum, and an online activity calendar. In addition tailored content based on models of health behavior via the website and mobile fully automated text messages. Cont: Access to Web site with information regarding cardiac rehabilitation, an online discussion forum, and an online activity calendar.	Change in median MET-min/week after 3 months from baseline Int: +4738 Cont: −3234
TXT2BFiT [28] (2016) Australia 9 months	$n = 248$ Int: 123 Cont: 125	Text E-mails Web sites	Int: Personalized set of text messages (8 per week) and weekly e-mails sent over 12 weeks emphasizing in addition to diet recommendations, physical activity. Monthly phone calls and text messages for 6 months after initial 12 weeks. Cont: 4 text messages over 12 weeks with recommendation regarding diet and increasing physical activity	Change in self-reported activity (MET-min/week) Int: +872 Cont: +797 ($p = 0.801$)
mActive [29] (2015) USA 18 weeks	n = 32 Int: 16 Cont: 16	SMS	Int: Smart texts 3 times/day aimed at individual encouragement and feedback by a fully automated, physician-written, theory-based algorithm Cont: Usual care	Change in number of daily steps Int: +2334 Cont: −200 ($p < 0.001$)
Buchholz et al. [30] (2016) USA 12 weeks	$n = 33$ Int = 33 Cont: No control group	SMS Pedometer	Int: Orientation session with a physical activity prescription. Podometers to track progress of physical activity and text messaging to deliver motivational texts and feedback. Cont: No control group	Change in minutes of walking daily: +80 min

Table 2 (continued)

Study cited, year of publication, country duration	Sample size	Technology used	Intervention	Results
Frederix et al. [31] (2015) Belgium 24 weeks	$n = 140$ Int: 70 Cont: 70	SMS E-mail	Int: Conventional cardiac rehabilitation + texts encouraging participants to gradually achieve predefined exercise training goals Cont: Conventional cardiac rehabilitation	Change in mean self-reported moderate activity, vigorous activity and walking (MET-min/week) Int: +996 Cont: −488
AIMFIT [32] (2015) New Zealand 8 weeks	$n = 51$ Int 1: 17 Int 2: 16 Cont: 18	Mobile app	Mobile apps that with an 8-week training program to improve fitness Int 1: Immersive app Int 2: Non immersive app Cont: Usual physical activities	Time difference to complete 1 mile fitness test compared to their baseline Int 1: −14 s Int 2: −9.81 s Cont: +14.28 s
It's LiFe! [33] Netherlands 9 months	$n = 199$ Int 1: 65 Int 2: 66 Cont: 68	A three-dimensional (3D) activity monitor Mobile app Web app	Int 1: Self-management support program (SSP) + use of the monitoring and feedback tool Int 2: SSP Int 3: Usual care	Change in moderate and vigorous activity (≥3METS) Int 1: 9.53 Int 2: −2.13 Cont: −1.73

Int intervention group, *Cont* control group, *Mobile app* mobile application, *MET* metabolic equivalents, *LIPA* low-intensity physical activity, *MIPA* medium-intensity physical activity

rehabilitation services, the intervention group also participated in a personalized 24-week mHealth program which included a Web site and frequent SMS to encourage patients to be physically active. The control group was offered standard cardiac rehabilitation services only. The absolute increase in the proportion of participants who became physically active was higher in the control group (13%) than the intervention group (3%).The two groups, however, were unequal in terms of baseline physical activity at the start of the study (28% in the intervention group and 11% in the control group).

The invention of biosensors has added objectivity in measuring physical activity. This was utilized in the TXT2BFIT study, mActive study, and studies by Buchholz et al. and Frederix et al. [28–31]. While the mActive study and the Buchholz et al. studies were limited to SMS and pedometers only, Frederix et al. and TXT2BFit also used e-mails and Web sites. The mActive study provided texts three times a day to provide encouragement and feedback based on pedometer readings to intervention group participants while the control group were asked to use the pedometers but were not provided any feedback. The intervention arm had a mean increase of 2334 steps while the control arm reported a decrease of 200 steps, suggesting that the feedback through SMS, rather than the pedometer, was responsible for the increase in physical activity. Participants in the study by Buchholz et al. reported an 80-min increase in daily activity. However, there was no control group for comparison. In the TXT2BFIT study, the control group only received the introduction to the study, while the intervention group received a 6-month combination of phone calls, text messages, e-mails, and access to a Web site with educational knowledge. At 9 months, there was a mean MET-min increase of 872 min in the intervention group and 797 min in the control group ($p = 0.801$). Results were more encouraging in the study of 140 participants by Frederix et al. The sum of mean self-reported moderate activity, vigorous activity, and walking increased by 996 MET-min/week in the intervention group and decreased by 488 MET-min/week in the control group.

Mobile applications, although popular commercially, have been studied infrequently. They were evaluated in the AIMFIT study and It'sLIFE study, both of which had three arms [32, 33]. The It'sLIFE study assigned participants to either a self-support management program (SSP) with a feedback tool, SSP alone or usual care. The SSP consisted of four individual consultations with a practice nurse over 6 months addressing awareness of the risks of physical inactivity and setting goals/targets. The feedback tool consisted of an activity monitor, mobile phone app, and a Web app. Participants could see their real-time activity results and history on the mobile phone and Web app and receive feedback, as it related to their personal goal. At the end of the study, the group in the SSP with feedback tool arm had an increase in their physical activity while the other two groups recorded a decrease. The AIMFit study compared immersive apps and non-immersive apps with a control group. Immersive apps aim to actively engage one's senses and remove distractions by making the application interactive (i.e., mobile games). The mobile apps used in the study, both immersive and non-immersive, were designed to increase fitness and the ability to run 5 km. Time taken to complete 1 mi. was used as the fitness test. Adjusted time taken to complete 1 mi. was reduced by 28.7 s in the immersive app group ($p = 0.20$) and by 24.7 s in the non-immersive app group ($p = 0.32$) as compared to controls.

Overall, short-term results of mHealth interventions that motivate participants to increase physical activity have been encouraging. Studies are difficult to compare since they differed not only in terms of the modality as well as the metrics used. Not surprisingly, all the studies discussed in this section were conducted in developed countries, given many interventions required expensive wireless devices to measure physical activity. Future studies need to assess whether mHealth interventions can engage participants in settings where public awareness and knowledge regarding the importance of physical activity is low. Studies also need to evaluate the effect on clinical outcomes, if any, of commercial applications and devices designed to increase physical activity levels.

Smoking Cessation (Table 3)

More than 1.1 billion people worldwide smoke tobacco [34]. Smoking cessation often requires multiple attempts and different strategies such as counseling sessions, support groups, and pharmacological agents, either alone or in combination. The role of mHealth in smoking cessation has mostly been in supporting the abovementioned strategies. On occasion, it has served as a self-management option for people willing to quit.

With the need to reinforce smoking cessation multiple times a day, SMS are a commonly studied mHealth tool. The purpose of SMS has been to assist participants in working towards a quit date and providing support through the process of smoking cessation. The recently published SMOKEFREEVET study, for example, was performed on 1470 veterans and required participants to decide on quit [35]. SMS were sent prior to and after the quit date with content based on the date selected. In addition, it also provided the option of receiving coping tips via SMS during an urge to smoke. After 5 weeks, 13% of all users reported abstinence from smoking with greater than 60% of users classified as high engagers (based on their frequency of requesting help via SMS) reporting abstinence. There was no control group for comparison. The Stop My Smoking (SMS) USA study and the study by Ybarra et al. in Turkey had similar study designs, but they included control groups that received text messages unrelated to smoking [36–38]. The SMS USA study was conducted on adolescents while Ybarra et al.'s study recruited adults who were willing to quit. The SMS USA study showed that the number of cigarette smoking days in the last 30 days decreased from 5.4 to 3.4 days in the intervention arm and from 5.0 to 3.9 days in the control group ($p < 0.05$). Abstinence 3 months after quitting among participants in the intervention arm was higher (40%) than control participants (30%) but was not statistically significant (adjusted odds ratio = 1.62, 95% confidence interval 0.82, 3.21). In Ybarra et al.'s study, the 3-month abstinence was higher in the intervention group (11%) than the control group (5%, $p = 0.24$), although the result also did not achieve statistical significance. The TXT2STOP study of 5800 participants in the UK used a similar design [39••]. The study reported continuous abstinence at 6 months to be higher in the intervention group (10.7%) as compared to the control group (4.9%, $p < 0.0001$). A study of 2638 participants tailored their SMS content based on the motivational factors identified by the participants themselves [40]. The control group continued to receive their usual care without any SMS. The primary outcome of 7-day smoking abstinence was not significantly different between the two groups. Whittaker et al. also added the use of biweekly video messages to tailored SMS but this change also did not result in a significant difference in continuous abstinence at 6 months between the intervention group (26.4%) and control group (27.6%, $p = 0.8$)[41]. The Text2Quit study used a combination of SMS, e-mail, and a Web portal to provide added support for participants. This resulted in a higher abstinence rate in the intervention group (11.1%) compared to the control group (5.0%, $p < 0.05$)[42].

Mobile phone applications have also been assessed in smoking cessation. McClure et al. used mobile apps to provide psychoeducational materials and guidance on smoking cessation [43]. While the program was designed for self-help in the control arm, the intervention arm received the same content through an adaptive and integrated program. This provided participants with on-demand, tailored advice for managing common nicotine withdrawal symptoms (i.e., cravings, cough, insomnia) and medication side effects (i.e., nausea, rash) via a secure messaging system. The advice offered was specific to the duration, intensity, and improvement of each symptom or side effect. Both groups also received verenicline. Abstinence rates at 5-month follow-up were 36% in the intervention group versus 24% among controls ($p = 0.42$).

The Tweet2Quit study extended the concept of support groups to twitter. Participants were recruited through the internet via advertisements intended for users who searched relevant phrases such as "nicotine patches" or "quit smoking." They were encouraged to use twitter to engage in daily discussions regarding smoking cessation in addition to having support in the form of feedback texts and nicotine patches [44]. The control group received nicotine patches and a referral to the smokefree.gov smoking cessation Web site. The study reported sustained abstinence at 60 days being higher in the intervention group (40.0%) compared with the control group (20.0%, $p = 0.017$).

The Crave-Out study evaluated a mobile gaming app as a potential adjunct to control urges. Participants were asked to play a multilevel, pattern challenge game at the time of a

Table 3 Summary of mHealth studies related to smoking cessation

Study cited, year of publication, country, duration	Sample size	Technology used	Intervention	Results
SmokefreeVET [35] (2016) USA 5 weeks	$n = 1470$ Int: 1470 Cont: No control group	SMS	Int: 2–5 texts sent daily over 8 weeks, starting 2 weeks prior and continuing for 6 weeks. Cont: No control group	Abstinence: 13 > 60% of users classified as high engagers reported abstinence
Mason et al. [36] (2016) USA 6 months	$n = 172$ Int: 87 Cont: 85	SMS	Int: Daily motivational interviewing-based peer network counseling messages Cont: Text messages covering general (non-smoking related) health habits.	Change in number of smoking days in past month Int: −2 (from 5.4 to 3.4) Cont: −1.1 (from 5.0 to 3.9
Ybarra et al. [37] (2012) Turkey 3 months	$n = 151$ Int: 76 Cont: 75	SMS	Int: Received program messages the day after enrollment and continued to receive messages daily through the end of the program. Cont: 1 text message per week reminding them they were in the study	Three-month cessation: Int: 11% Cont: 5% ($p = 0.24$)
Stop My Smoking (SMS) USA [38] (2013) USA 3 months	$n = 164$ Int: 101 Cont: 63	SMS	Int: Four messages daily + buddy (another person in the program that a participant was assigned to so they could text) + on demand text messages to manage craving Cont: Texts unrelated to smoking cessation	Quit at 3 months Int: 40% Cont: 30% (odds ratio = 1.62, 95% confidence interval:0.82, 3.21)
txt2stop [39••] (2011) UK 6 months	$n = 5792$ Int: 2911 Cont: 2881	SMS	Int:5 text messages a day for the first 5 weeks and then three a week for the next 26 weeks with motivation and behavior change techniques Cont: Text messages unrelated to quitting.	Continuous abstinence at 6 months: Int: 10.7% Cont: 4.9% ($p < 0.0001$)
Haug et al. [40] (2013) Switzerland 4 weeks	$n = 755$ Int: 372 Cont: 383	SMS	Int: 2 weekly text messages tailored to the data of the online and the SMS text message assessments Cont: No intervention	4-week point prevalence abstinence: Int:6.3% Cont: 5.5% ($p = 0.92$)
Whittaker et al. [41] (2011) New Zealand 6 months	$n = 226$ Int: 110 Cont: 116	Video message	Int: Automated package of tailored video and text messages over 6 months + extra messages on demand to beat cravings Cont: Also set a quit date and received a general health video message sent to their phone every 2 weeks	Continuous abstinence at 6 months: Int: 26.4% (29/110) Cont: 27.6% (32/116) ($p = 0.8$).
Text2Quit [42] (2014) USA 6 months	$n = 503$ Int: 262 Cont: 241	SMS E-mail Web portal	Int: Automated, bidirectional text messages. E-mails and a Web portal offered as supportive features. Cont : Web link to with quitting smoking information	Point prevalence abstinence Int: 11.1% Cont: 5.0% ($p < 0.05$)
McClure et al. [43] (2016) USA 5 months	$n = 66$ Int: 33 Cont: 33	Mobile app	Int: Interactive and adaptive on-demand, tailored advice for nicotine withdrawal symptoms and medication side effects with secure messaging + psychoeducational materials and guidance on smoking cessation via a mobile app Cont: Self-help program providing psychoeducational materials and guidance on smoking cessation via a mobile app	Abstinence at 5 months Int: 36% Cont: 24% ($p = 0.42$)
Tweet2Quit [44] (2016) USA 60 days	$n = 135$ Int: 65 Cont: 70	Twitter Text	Int: Nicotine patches and smokefree.gov Web site links + Twitter-based peer to peer support and daily discussion topics + daily engagement feedback via texts Cont: Nicotine patches and smokefree.gov Web site links	Sustained abstinence (7-day point prevalence abstinence) Int: 26/65 (40%) Cont: 14/70 (20%)
Crave-Out [45] (2016) USA	$n = 30$ Int: 30	Mobile phone gaming app	Int: Multilevel, pattern challenge game. Smoking urge assessed before and after game	Measurement of QSU-Brief Pregame mean: 3.24 Postgame mean: 2.99 ($p = 0.11$)

Int intervention group, *Cont* control group *SMS* short messaging service, *Mobile app* mobile application, *QSU* Questionnaire of Smoking Urges

smoking urge [45]. Pregame urge, as assessed by the Questionnaire of Smoking Urge-Brief (QSU-Brief), was found to be higher than post game urge ($p = 0.11$), hence suggesting a lower but non-significant reduction in craving.

In summary, it appears that mHealth interventions for smoking cessation were well planned and executed. Tailored messages based on the stage of quitting were frequently employed and assistance was often provided to cope with smoking urges. Even though the intervention groups did better than control groups in some studies, the absolute rates of smoking cessation reported remain low. The Tweet2quit study outlines a pragmatic way forward with a model that enrolls participants in virtual support groups. Future challenges for mHealth smoking cessation lie in engaging smokers who are unwilling to quit.

Conclusion

mHealth has been increasingly studied as an aid in the management of diabetes, physical inactivity, and smoking. Results from these studies suggest a potential role as both primary interventions and supplemental tools to further enhance the efficacy of conventional strategies. The choice of intervention remains heavily dependent on resource availability.

There remain gaps in our knowledge in regards to the impact of mHealth interventions on long-term cardiovascular outcomes. Future studies are also needed to assess the efficacy of interventions that target multiple cardiovascular risk factors.

Compliance with Ethical Standards

Conflict of Interest Hasan Rehman, Ayeesha K. Kamal, Saleem Sayani, and Anwar T. Merchant declare that they have no conflicts of interest.

Pamela B. Morris declares being on the advisory boards for Amgen, AstraZeneca, and Sanofi Regeneron.

Salim Virani declares being an Associate Editor for Innovations, ACC.org.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- • Of importance
- •• Of major importance

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