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Mobile health in preventive cardiology: current status and future perspective

Michael Kozik[a,b,c], **Nino Isakadze**[a,b,c,d], **Seth S. Martin**[a,b,c,d]

[a]Department of Medicine, Division of Cardiology, Johns Hopkins University School of Medicine

[b]Ciccarone Center for the Prevention of Cardiovascular Disease, Digital Health Innovation Laboratory, Johns Hopkins University School of Medicine

[c]Johns Hopkins Center for Mobile Technologies to Achieve Equity in Cardiovascular Health (mTECH)

[d]Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland, USA

Abstract

Purpose of review—Despite cutting edge acute interventions and growing preventive strategies supported by robust clinical trials, cardiovascular disease (CVD) has stubbornly persisted as a leading cause of death in the United States and globally. The American Heart Association recognizes mobile health technologies (mHealth) as an emerging strategy in the mitigation of CVD risk factors, with significant potential for improving population health. The purpose of this review is to highlight and summarize the latest available literature on mHealth applications and provide perspective on future directions and barriers to implementation.

Recent findings—While available randomized controlled trials and systematic reviews tend to support efficacy of mHealth, published literature includes heterogenous approaches to similar problems with inconsistent results. Some of the strongest recent evidence has been focused on the use of wearables in arrhythmia detection. Systematic reviews of mHealth approaches demonstrate benefit when applied to risk factor modification in diabetes, cigarette smoking cessation, and physical activity/weight loss, while also showing promise in multi risk factor modification via cardiac rehabilitation.

Summary—Evidence supports efficacy of mHealth in a variety of applications for CVD prevention and management, but continued work is needed for further validation and scaling. Future directions will focus on platform optimization, data and sensor consolidation, and clinical

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Correspondence to Seth S. Martin, MD, MHS, FACC, FAHA, FASPC, Associate Professor, Division of Cardiology, Department of Medicine, Johns Hopkins University School of Medicine; Co-Director, Johns Hopkins Center for Mobile Technologies to Achieve Equity in Cardiovascular Health (mTECH), an AHA SFRN Center for Health Technology and Innovation; Director, Digital Health Innovation Laboratory, Ciccarone Center for the Prevention of Cardiovascular Disease, 600N. Wolfe Street, Carnegie 591, Baltimore, MD 21287, USA. Tel: +1 610 331 3842; fax: +1 410 367 2224; smart100@jhmi.edu.

Conflicts of interest
S.S.M. is a coinventor on a system to estimate LDL cholesterol levels, patent application pending. Under a license agreement between Corrie Health and the Johns Hopkins University, the University owns equity in Corrie Health and the University and Dr Martin are entitled to royalty distributions related to technology described in the study discussed in this publication. In addition, S.S.M. is a founder of and holds equity in Corrie Health. This arrangement has been reviewed and approved by the Johns Hopkins University in accordance with its conflict of interest policies. S.S.M. has served as a scientific consultant to Amgen, AstraZeneca, DalCor Pharmaceuticals, Esperion, Kaneka, Sanofi, and 89bio.

workflow integration. Barriers include application heterogeneity, lack of reimbursement structures, and inequitable access to technology. Policies to promote access to technology will be critical to evidence-based mHealth technologies reaching diverse populations and advancing health equity.

Keywords

digital medicine; mobile health technology; preventive cardiology; telehealth; wearable technology

INTRODUCTION

In the years leading up to the COVID-19 pandemic, mobile health technologies (mHealth) were already emerging as a promising avenue to enhance cardiovascular disease (CVD) prevention. Not only may mHealth technologies help in identification of unidentified CVD risk, they may enable the acquisition of longitudinal and personalized data capture to tailor management while empowering patients with accessible resources for education and behavioral support. Now, with the ubiquitous adoption of telehealth necessitated by the pandemic, mHealth strategies are poised to become essential to daily practice. While this may be inevitable, mHealth suffers from a lack of robust clinical trials to support widespread implementation. In this new field, continued research and investment in mHealth related clinical trials will be necessary to foster legitimacy and routine clinical implementation, while fueling enthusiasm for further study and innovation. Policy makers and insurance companies can promote equal access to mHealth for patients with diverse socioeconomic backgrounds who are otherwise disadvantaged due to barriers such as cost and education. Further, legitimizing the mHealth approach within the scope of cardiology can open avenues for incorporating such tech across the medical field at large.

In this review, we will explore how mHealth strategies have been evaluated and implemented in the prevention and management of CVD and discuss how the role of mHealth may grow in the postpandemic era.

BACKGROUND STATISTICS

The emergence of mHealth as a viable clinical tool has been facilitated by the growing widespread adoption of smartphones. According to a review of the 2018 Health Information National Trends Survey Database, 73% of individuals with or at risk for CVD risk owned a smartphone, compared with 89% in individuals without CVD risk factors or established CVD. Notably, smartphone ownership in the CVD risk group has increased compared with 63% in 2014. Likewise, the prevalence of those having a health app has increased from 36% in 2014 to 48% in 2018 [1]. Despite this, 38% used a smartphone or tablet to make a health decision, 32% used a smartphone or tablet to aid in discussion with a clinician, and only 23% shared information from a smartphone/wearable with a clinician [1]. Given these statistics are for those with CVD risk, the discrepancy between those in possession of a smart device and those who use it for mHealth suggest a significant potential for implementation of novel preventive strategies.

Studies looking at demographic factors and mHealth uptake have clearly shown disparities in smartphone ownership between those with CVD risk and those without [1]. Younger age, higher education, higher income, health insurance coverage, and urban environment are associated with greater odds of health app ownership, while male sex has a higher association with use of sensors and wearable devices [1-4]. Unsurprisingly, these same demographics also factor into predicted success with telemedicine visits [5,6].

CURRENT STRATEGIES

mHealth encompasses a wide array of communication platforms and mobile devices. These range from smartphones and mobile applications (apps), to wearable technologies such as the Apple Watch, FitBit, and other sensors capable of monitoring physical activity, heart rate, and even ECG. The goals of mHealth technology for CVD span prevention, early disease detection, disease management, and patient engagement/self-care/education to remote monitoring approaches and tools to augment clinician ability to care for patients. Demonstrably successful mHealth strategies incorporate patient-driven data collection met with personalized feedback via communication platforms, such as short media service (SMS) messages [7,8]. To this point, systematic reviews have demonstrated that the use of mHealth can reduce CVD outcomes and have a positive impact on CVD risk factors, and the American Heart Association has made efforts to recognize this and drive innovation in this sector [9,10].

We will discuss strategies as they pertain to primary prevention and secondary prevention. Tables 1 and 2 highlight notable randomized control trials (RCTs) and meta-analyses for each.

Primary prevention

The mHealth strategies for primary prevention are aimed at risk factor identification and modification prior to the development of CVD. As risk factor modification often relies on behavior change, a wide range of approaches have been developed to support healthy lifestyle practices. The spectrum of approaches includes SMS-based coaching programs, internet-based or app-based data educational and data entry resources, wearable activity monitors, and complex integrated multimedia programs.

SMS-based coaching programs account for some of the earlier pre smartphone mHealth interventions that were explored for multiple different preventive health applications spanning obstetrics, pediatrics, and general adult medicine [11]. The breadth of application has derived from studies pertaining to smoking cessation, with multiple RCTs and Cochrane meta-analyses supporting improved short-term and long-term quit rates from fixed scheduled messaging [12-15]. Favorable features of such SMS-based programs include fixed scheduled messaging, providing tips on preparing to quit as well as managing urges after cessation, and the ability to text for more behavioral support [16]. Other text messaging interventions included periodic check-ins on quit status, tailored messages based on quit status, optional quit buddies, polls and quizzes, and support networks [13]. Similar principles for SMS-based coaching have been utilized for strategies aimed toward weight loss, activity promotion, as well as diabetes and blood pressure control with consistently demonstrated success when comparing groups receiving personalized feedback from mHealth applications to those utilizing such applications only for data tracking [10,17,18,19■].

Compared with the available body of literature supporting SMS-based feedback messaging, the newer internet-based and app-based mHealth CVD prevention strategies suffer from a lack of high-quality evidence. For example, with smoking cessation interventions, internet-based and app-based strategies have demonstrated superiority to passive literature resources, but the available RCTs and meta-analyses have failed to demonstrate improved efficacy over SMS-based interventions [13-15,20]. Meanwhile, commercially developed wellness apps like MyFitnessPal have likewise suffered from a lack of robust studies supporting clinical efficacy [10]. Specifically, MyFitnessPal, which utilizes goal setting, self-monitoring of macronutrients and calories, and feedback to facilitate weight loss goal-tracking, has been shown to achieve no significant difference in weight change when directly studied in an RCT [21].

Other technologic advancements have led to consumer adoption of activity tracking devices ranging from smartphones or wearable wristbands capable of monitoring total daily steps, to wearable devices capable of monitoring degree and duration of aerobic activity via heartrate monitoring. Commercial fitness apps have managed to automatically incorporate fitness data into goals. With MyFitnessPal, wearable-based activity tracking information is integrated with diet and weight loss goal tracking. Studies related to app-based activity promotion interventions have consistently demonstrated that mHealth strategies can increase physical activity in the short term. Notably, RCTs support the pervading theme of benefit derived from personalized motivational communications [8,10,22-27]. Future multimedia applications look to incorporate complex data from other wearable devices, such as continuous glucose monitors (CGMs) [28], as will be discussed below.

Ultimately, the available literature provides promising RCTs and meta-analyses broadly supporting mHealth in primary prevention applications, especially where personalized feedback is included [8,9,10,29]. However, inconsistent RCT results and limited quantity of high-quality evidence highlights such limitations as diversity of interventions, readiness of study participants, and lack of studies comparing user satisfaction across platforms, all reinforcing the need for further study and platform optimization.

Secondary prevention

In many ways, primary prevention mHealth strategies have served as building blocks for integrated secondary prevention and chronic disease management mHealth strategies. Studied programs tend to incorporate multimedia approaches with app-based and internet-based applications that utilize SMS-based notifications and wearable technology.

For the secondary prevention of coronary artery disease related morbidity and mortality, cardiac rehabilitation programs have shown significant benefit toward preventing unplanned readmission following hospitalization for acute myocardial infarction. Despite this benefit, utilization rates are low [30]. Studies on mHealth-based cardiac rehabilitation programs have suggested that mHealth can reach patients in more convenient settings with comparable, if not better, results when compared with center-based approaches [31-33]. mHealth-based cardiac rehabilitation approaches are similar to the multimedia approaches discussed for improving physical activity, often incorporating app-based platforms with educational references, self-monitored vitals charting, and medication tracking, with SMS or push-style notifications for encouragement and adherence reminders, as well as wearable devices for monitoring heartrate or physical activity. On the contrary, while some RCTs have shown benefit with mHealth-based cardiac rehabilitation [32], other RCTs failed to achieve improvements in their primary outcomes [34,35]. The discrepancy of results highlights the heterogeneity of mHealth approaches. Further study may help optimize future mHealth approaches, and multiple RCTs are underway [36].

mHealth has also been studied among patients with heart failure. Advanced technologies such as the permanently implanted pulmonary artery pressure monitoring CardioMEMS system have been studied for early detection of heart failure decompensation [37]. Noninvasive monitoring via integrated mHealth platforms may avoid procedural risk while improving accessibility. Unfortunately, there is limited literature on this subject, with meta-analyses showing inconsistent evidence of impact on clinical end-points [38,39].

Arrhythmia detection has fueled exciting mHealth developments within the field of wearables. Due to the paroxysmal nature of arrhythmias, the field has historically relied on intermittent Holter monitors, as well as externally applied event monitors and implantable loop recorders for detection and characterization of arrhythmia [8,40]. mHealth has officially cemented a role in the field with Food and Drug Administration (FDA) approval of the Apple Watch, Kardia Band, and Kardia Mobile 6L devices for detection of atrial fibrillation [41■,42]. Coupled with the emergence of atrial fibrillation management apps [43], these devices present potential applications ranging from new diagnosis of atrial fibrillation and postablation monitoring to facilitation of pill-in-pocket management strategies and prevention of emergency department visits or hospitalizations for cardioversion in cases where sinus rhythm is restored prior to presentation [41■,44]. Notably, the ongoing HEARTLINE study (heartlinestudy.com) will investigate if stroke and thromboembolic events can be reduced by early atrial fibrillation diagnosis via Apple Watch. Promising results from this study could have enormous implications to mHealth adoption and reimbursement.

DISCUSSION

Future applications

Often, information collected from mHealth devices requires manual data entry from the patient or clinician, which can limit the amount of potential data transmitted. As of 2020, large institutions such as Duke and Stanford have partnered with the Epic Electronic Health Record (EHR) system to incorporate smartphone Apple Healthkit and Dexcom G4 CGM data into the EHR clinician workflow [45]. These efforts were in pilot stages as early as 2016 [46], with further study ongoing. While this may add to the vast amount of data interpretation already required for patient care, these efforts may lead to streamlined incorporation of mHealth data as development continues. Regardless, efforts toward mHealth-EHR integration are still in early stages and further study will be necessary.

Consolidation of wearable sensors is likewise an appealing field of future study. For example, using similar technology to the Apple Watch, remote vital monitoring devices have been developed to monitor multiple parameters via a single external device [47]. Meanwhile, future development of CGM-like wearable biosensors capable of analyzing sweat, tear, saliva, or interstitial fluid composition could have a role in monitoring surrogates of serum sodium, brain natriuretic peptide, potassium, or creatinine for chronic disease monitoring in heart failure [48].

Barriers

Despite advancements in mHealth technology and growing supporting its various applications in CVD prevention and chronic disease management, implementation into daily practice has been slow. While integration of mHealth and EHR and consolidation of wearable sensors are promising efforts toward streamlining implementation, barriers to uptake exist.

Access to mHealth technologies represents the foremost barrier to uptake by patients and implementation by clinicians. Previously mentioned demographics suggest advanced age, lower education, lower socioeconomic status, and rural environments are associated with decreased uptake. Concerningly, these demographics also portend susceptibility to CVD. Increasing access to mHealth would require creative solutions toward each inequity. For aged and low education populations, advanced onboarding sessions by dedicated tech support teams may be beneficial. However, such measures with direct tech support may be costly and time consuming. A reasonable study might weigh passive tech support with onboarding videos compared with active support with person-to-person coaching. If proven effective, using onboarding videos could reduce the burden of hiring and maintaining staff. In addition, new apps or multimedia mHealth programs could incorporate representative focus groups in the early design process to guide the development team toward an easily adoptable product [49]. Despite efforts to optimize, some patients may be hindered by cost and access to broadband or mobile networks.

For clinicians, the litany of information provided by mHealth products can be overwhelming, of uncertain accuracy, and impractical to integrate into clinical workflow in a highly time constrained clinical environment. Streamlined integration with the EHR might minimize this burden, though high levels of friction in EHR workflow is already a major hurdle for clinicians. However, with frequent updates provided between visits, clinician lack the framework for reimbursement of mHealth data review and services performed between visits. A robust body of research supporting mHealth technology has the potential to facilitate formal coverage by health insurers. In addition, demonstrated benefit of mHealth along with telemedicine may bolster policy advocacy for lowering cost and increasing access to broadband internet and highspeed mobile data networks nationwide. The Federal Communications Commission’s Lifeline program to provide subscribers a discount on broadband Internet service from participating wireline or wireless providers is a step in the right direction.

The regulation of apps presents an intriguing set of problems. Currently, the US FDA regulates a specific subset of apps that are intended for use with medical devices or for converting mobile platforms into regulated medical devices [50]. Consequently, the majority of health apps are not subject to regulation. Meanwhile, as of 2018, roughly half of the 3.4 billion global smartphone users have downloaded a health app, with the majority of consumers neglecting to check app publisher credibility [8,50,51]. Marketplace dilution with ineffective apps has numerous potential consequences. First, increased heterogeneity threatens meta-analyses, potentially diminishing the overall quality of evidence. Second, it could overwhelm patients with options. This issue is further compounded when clinicians lack familiarity with what options are publicly available and which of those are supported by quality evidence. Third, poorly optimized apps could discourage future use altogether. Finally, many studied apps are not commercially available, while many commercially available apps have not been appropriately studied [10]. These issues suggest need for either increased oversight from governing bodies like the FDA, or endorsement by guidelines of professional organizations. Alternatively, health systems could integrate evidence-based mHealth technologies into their EHR. Any of these solutions may hinder creative development, but may prove necessary to ensure safety, efficacy, and uptake.

CONCLUSION

The future of mHealth in preventive cardiology promises exciting advancements in EHR-integrated multimedia programs that incorporate smartphone capabilities with cutting-edge wearables. Even with ongoing technology advancements, relatively lowtech SMS-based interventions have consistently shown benefit across a wide array of studied mHealth applications. In addition to furthering technology advancement, continued research supporting mHealth use will serve to support incorporation into clinical practice guidelines and facilitate reimbursement for patients and clinicians alike. Policy questions, such as mHealth app development oversight and expanding equitable mHealth access, will shape the future. With the COVID-19 pandemic forcing patient and clinician familiarity with telehealth, discussions on implementation and policy are likely to reach the forefront of medical debate sooner than previously expected.

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KEY POINTS

- Available evidence supports efficacy of mHealth in a variety of applications for CVD prevention and management.
- Food and Drug Administration approval of wearable sensors for applications such as atrial fibrillation detection is a milestone for the mHealth field, solidifying the validation of commercial wearables in healthcare applications.
- Future mHealth applications are expected to include multimedia platforms that include app-based programs and wearable data-collecting devices integrated with Electronic Health Record interfaces.
- Socioeconomic status and age remain significant barriers to patient mHealth uptake, while lack of reimbursement structures and application heterogeneity are barriers to clinician utilization.
- Policies to promote access to technology will be critical to evidence-based mHealth technologies reaching diverse populations and advancing health equity.

Table 1.

Selected studies for mobile health technology in primary prevention of cardiovascular disease

Risk factor	Study name/ authors	Study design	Sample size RCT no. enrolled, or sys. review studies included)	Intervention	Outcomes	Findings
Aggregate	Widmer *et al.* [9]	Systematic review	51 studies	mHealth interventions compared with usual care alone	CVD outcomes, risk factors (BP, lipids, BMI)	Significant reduction in CVD outcomes; concomitant reductions in weight, but not BP
Smoking	Txt2Stop [12]	RCT	5800 enrolled	SMS (regularized behavioral support vs. unrelated messages)	Smoking abstinence (biochemically verified)	Continuous abstinence improved
	OnQ [14]	RCT	3530 enrolled	SMS-based vs. internet-based cessation platform	Smoking abstinence	Improved abstinence compared with control; no difference between SMS and internet
	Taylor *et al.* [15]	Systematic review (Cochrane)	67 studies	mHealth smoking cessation interventions	Smoking abstinence	Internet-based interventions moderately more effective than passive interventions; no evidence supporting internet over other active strategies (i.e. SMS)
	Whittaker *et al.* [13]	Systematic review (Cochrane)	5 studies	Interactive smoking cessation apps compared with passive interventions	Smoking abstinence	No evidence supporting interactive apps over passive apps, with very low certainty
	MobileQuit [20]	RCT	1271 enrolled	Combined app-SMS vs. internet-based cessation interventions	Primary: Smoking abstinence Secondary: user satisfaction	Significant improvement in abstinence and satisfaction for app-SMS group compared with internet group
Weight loss	mFit (MyFitnessPal) [21]	RCT	212 enrolled	MyFitnessPal plus usual care vs. usual care alone	Primary: Weight loss Secondary: app satisfaction, app use, SBP	No difference in weight loss; high satisfaction reported; use frequency dropped after first month
	Siopis *et al.* [25]	Systematic review	14 studies	SMS (variety of weight loss programs with regular SMS communications vs. program without communication)	Weight loss	Text messaging interventions can promote weight loss in short-term, long-term data lacking
	LOSE IT [26]	RCT	196 enrolled	Smartphone-based activity and weight tracking with competitive vs. noncompetitive goal tracking compared with no goal tracking. Also compared EHR-integrated data collection to non-EHR-integrated	Weight loss	Activity and weight goal tracking produces statistically significant weight loss; no difference in competitive vs. noncompetitive arms; no difference in EHR-integrated vs. non-EHR-integrated subgroup
	Senecal *et al.* [27]	Retrospective observational	250 000 individuals	App-guided weight-loss program with dietary replacement and wireless scale incorporation	Weight loss	Significant short-term and midterm weight loss
Physical inactivity	mActive [23]	RCT	48 enrolled	Smartphone-based activity tracker with smart SMS messages vs. without SMS vs. blinded activity tracking (control)	Mean daily step count	Improved step count with smart SMS and activity tracking; no difference between activity tracking without SMS and control

Risk factor	Study name/ authors	Study design	Sample size RCT no. enrolled, or sys. review studies included)	Intervention	Outcomes	Findings
BP	Tucker *et al.* [17]	Systematic review	25 studies	BP self-monitoring alone vs. with cointerventions (physician feedback, medication changes, education)	BP control	BP monitoring with cointerventions leads to improved control; self-monitoring alone is not associated with improved control
Lipid control	Akbari *et al.* [29]	Systematic review	18 studies	mHealth interventions in patients with metabolic syndrome and related disorders	Lipid profile changes	mHealth associated with improved total and LDL cholesterol
Diabetes	Kroger *et al.* [28]	Retrospective	363 records reviewed	Diabetic self-care and monitoring with CGM devices	A1C reduction	CGM use was associated with a small but statistically significant improvement in A1C control

BP, blood pressure; CGM, continuous glucose monitor; CVD, cardiovascular disease; EHR, Electronic Health Record; mHealth, mobile health technologies; RCT, randomized control trial; SMS, short media service.

Table 2.

Selected studies for mobile health technologies in secondary prevention of cardiovascular disease

Targeted disease	Study name/ authors	Study design	Sample size (RCT no. enrolled, or sys. review studies included)	Intervention	Outcomes	Findings
Atherosclerotic disease	Varnfield *et al.* [32]	RCT	120 enrolled	Smartphone-based home CR vs.traditional center-based CR	Primary: 6MWT Secondary: CR uptake and completion	mHealth CR and traditional CR both showed improved 6MWT; mHealth improved CR uptake and completion compared with traditional
	HEARTSTRONG [34]	RCT	1509 enrolled	mHealth-based medication reminders, social support, and lottery incentives vs. usual care in post-Acute Myocardial Infarction patients	Primary: time to first vascular rehospitalization or death Secondary: time to first all-cause rehospitalization, total number of repeated hospitalizations, medication adherence, and total medical costs	No significant improvement in vascular readmissions or medication adherence
	HONOR [35]	RCT	200 enrolled	Home-based exercise intervention with wearable activity monitor and telephone coaching compared with usual care for patients with peripheral artery disease	Primary: 6MWT Secondary: pain, functional capacity, social satisfaction scores	Home-based mHealth exercise intervention failed to demonstrate improvement in 6MWT or other secondary outcomes
	Wongvibulsin *et al.* [33]	Systematic review	31 studies	mHealth-based CR strategies	Exercise capacity, rehospitalizations, lipid profile, weight, nutrition, program, adherence, satisfaction, psychosocial wellbeing	mHealth-based CR as effective as traditional CR in improving outcomes, whether as adjunct or alternative, with potential to increase access and participation in CR
	MiCORE (ongoing) [36]	Non-RCT with propensity matched control	200 enrolled	Corrie Health App-based home CR with integrated smart BP monitor and apple watch vs. traditional CR	Primary: readmissions within 30 days Secondary: death, ED visits, and hospital observations within 30 days of discharge, med adherence, attendance at followup, program engagement, satisfaction, cost-effectiveness	*Study ongoing*
Heart failure	CardioMEMS [37]	RCT	550 enrolled	Daily wireless PAP monitoring and standard of care vs. standard of care alone in NYHA symptom class III heart failure (HF) patients with implanted wireless hemodynamic monitor	Primary: HF-related hospitalizations at 6 months Secondary: days alive outside hospital at 6 months, change in baseline PAP, functional capacity score	Wireless monitoring was associated with significant reduction in hospitalizations as well as mean PAP, more days alive outside hospital, and better quality of life compared with control
	Cajita *et al.* [38]	Systematic review	10 studies	mHealth-based management strategies in HF	Mortality, hospitalizations, length of stay, functional capacity, quality of life, self-care	Inconsistent results failed to demonstrate significant benefit

Targeted disease	Study name/ authors	Study design	Sample size (RCT no. enrolled, or sys. review studies included)	Intervention	Outcomes	Findings
	Allida *et al.* [39]	Systematic review (Cochrane)	5 studies	mHealth education interventions in HF	HF knowledge, hospitalization rates, quality of life, self-efficacy, and self-care	Very low quality of evidence with inconsistent results across all outcomes
Arrhythmia	Apple Heart Study [42]	Large-scale siteless study	Up to 500,000	Detection of AF in patients using Apple Watch Series 4 or later	Primary: detection of AF Secondary: self-reporting to clinicians, concordant AF with app notification	Achieved primary outcome with FDA approval of the Apple Watch for AF detection
	Heartline Study (ongoing, clinical trial NCT04276441)	Observational prospective cohort	*Actively enrolling as of 2020*	Apple Watch-based AF detection	Primary: early detection of AF, days on anticoagulation Secondary: time to major adverse cardiac event, AMI, stroke, and thromboembolic events	*Study ongoing*

6MWT, 6-min walk test; AF, atrial fibrillation; AMI, acute myocardial infarction; CR, cardiac rehab; ED, emergency department; FDA, Food and Drug Administration; HF, heart failure; mHealth, mobile health technologies; NYHA, New York Heart Association; PAP, pulmonary artery pressure; RCT, randomized controlled trial.