

Using Mobile Technology for Cardiac Rehabilitation: A Review and Framework for Development and Evaluation

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Background

Ischemic heart disease (IHD) is the leading cause of death in the United States.¹ Cardiac rehabilitation is an evidence-based, cost-effective, multidisciplinary program of individual patient risk factor assessment and management, exercise training, and psychosocial support for patients with heart disease that reduces mortality by 12% to 34% (Table 1).^{2–6} Cardiac rehabilitation is recommended by American Heart Association (AHA) and the American College of Cardiology (ACC) Guidelines for patients after myocardial infarction (MI), percutaneous coronary intervention (PCI), or coronary artery bypass surgery (CABG).⁷ However, cardiac rehabilitation is dramatically underutilized, with only 14% to 31% of eligible patients participating.⁸ Barriers to participation include low referral rates, patient difficulty attending center-based rehabilitation sessions, and cost.⁹ Recently, an AHA Presidential Advisory called for a reengineering of cardiac rehabilitation to enhance access, adherence, and effectiveness.¹⁰ It is clear that new strategies are needed for the delivery of cardiac rehabilitation.

Mobile technology has the potential to overcome barriers to access to cardiac rehabilitation and may be a useful tool for increasing participation. Mobile health provides the opportunity to improve access to health promotion interventions and has the unique advantage of being able to influence health behaviors in real-time.¹¹ Of smartphone users, 86% have used their mobile phone to access just-in-time information in the past month.¹² Through mobile technology, a user can receive and interact with information, record and review data, receive

automated feedback, and connect with other users or healthcare providers.

Mobile health interventions also have the potential to reach a wide segment of the population. Among American adults, 91% own a mobile phone and 56% own a smartphone.¹³ Mobile health applications are increasingly popular, with \approx 1 in 5 smartphone users having downloaded a mobile health application.¹⁴ Among minorities, a group with traditionally low participation in cardiac rehabilitation, evidence suggests that uptake of smartphones is high, and that minorities are more likely than nonminority populations to use their smartphones to access health information.^{13,14} In addition, those without home broadband internet access are using their smartphones to access the internet, suggesting that the mobile platform could have even greater penetration than a purely internet-based platform for reaching disadvantaged populations.¹⁵ While older adults are less likely than younger adults to use mobile technology, recent trends have shown significant increases in internet use and mobile phone ownership by older adults.^{14,16}

Use of mobile phone applications can increase motivation and physical activity in generally healthy populations.^{17,18} Studies of mobile applications have shown a high degree of acceptability and reasonable efficacy for increasing physical activity and weight loss. In patients with diabetes, mobile applications for self-management have been shown to improve blood glucose control.¹⁹ These findings raise the possibility that mobile applications could be used for promoting physical activity and self-management among patients with IHD who are eligible for cardiac rehabilitation.

However, little is known regarding the use of mobile applications for cardiac rehabilitation. As these mobile applications begin to emerge, it will be important to have a standard framework for their evaluation. In this review, we examine the existing literature on the use of mobile technology for cardiac rehabilitation and propose a framework for developing and evaluating mobile applications for cardiac rehabilitation.

Literature Search

We performed a PubMed search from January 1, 1993 to September 2, 2013 for relevant articles using the following

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Table 1. Core Components of Cardiac Rehabilitation^{2,3}

1. Patient assessment
2. Nutritional counseling
3. Weight management
4. Blood pressure management
5. Lipid management
6. Diabetes management
7. Tobacco cessation
8. Psychosocial management
9. Physical activity counseling
10. Exercise training

search strategy: (“telemedicine”[Mesh] OR mobile OR internet OR web OR smartphone OR mHealth OR eHealth) AND (“cardiac rehabilitation” OR [{cardiac OR cardiovascular OR heart} AND “secondary prevention”]). The search returned 150 studies. One author (A.B.) reviewed the abstracts of all articles for inclusion and exclusion criteria. Included studies were those that involved mobile phone interventions for cardiac rehabilitation for patients with IHD. Protocols and completed studies were eligible for inclusion. Studies were excluded from this review if they were not available in English, did not include an intervention with evaluation of health outcomes, did not have a mobile phone component, did not enroll adult patients with IHD, or did not have a physical activity component (Figure). Articles reporting content and technical development of included studies were noted. Review

articles were excluded from the analysis, but references were examined for other articles meeting inclusion and exclusion criteria. References of included studies were also reviewed to identify other articles meeting inclusion and exclusion criteria.

Existing Studies

We identified 3 completed, published studies involving mobile phone technology for the delivery of cardiac rehabilitation that evaluated health outcomes in patients with IHD (Table 2).^{20–22} Though relatively small and not explicitly based on behavior change theory, these studies supported the feasibility and acceptability of the use of mobile technology for cardiac rehabilitation. No studies have evaluated efficacy with regard to cardiovascular events. However, several groups of investigators have published promising study designs for evaluating the use of mobile technology for delivery of cardiac rehabilitation (Table 3).^{23–26} These studies expand on the existing literature by including the core components of cardiac rehabilitation, basing their interventions on behavior change theory, evaluating a wide array of patient-centered health outcomes, and employing randomized clinical trial designs (to reduce bias due to confounding from baseline differences in mobile versus traditional groups).

Proposed Framework

Although mobile health applications are increasingly prevalent, they are often not based on evidence-based practices or rigorously studied with regard to their impact on health

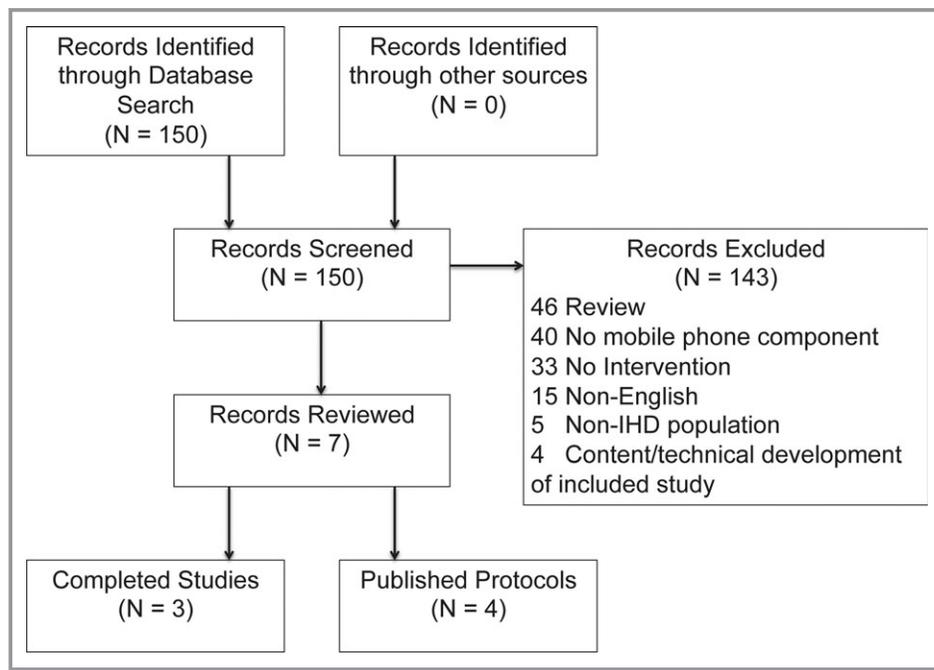


Figure. Flow diagram of literature search and selection of studies for review. IHD indicates ischemic heart disease.

Table 2. Completed Studies of Mobile Technology for Cardiac Rehabilitation for Ischemic Heart Disease

Author/Year/ Country	Design/ Duration	Theoretical Foundation	Non-mHealth Components	mHealth Components	Intervention	Control	Outcomes
Worringham ²⁰ 2011 Australia	Observational 6 weeks	None	Telephone contact pre- and postexercise session with provider.	Smartphone, smartphone application, single-lead ECG, GPS with real-time transmission to providers.	Monitored exercise training (walking) 3 times weekly assisted by smartphone application. (N=6)	None	<i>Usability:</i> 80% of sessions no technical problems. Ease of use rated 4.8/5 (95% CI 4.6 to 5.0). <i>Participation:</i> Completed 80% of scheduled exercise sessions. <i>Exercise Capacity:</i> 6MWT improved from 524 to 637 m ($P=0.009$). <i>Health Status:</i> SF36 Physical Health increased from 50.0 to 78.4 ($P=0.03$), Mental Health unchanged. <i>Events:</i> None
Korzeniowska-Kubacka ²¹ 2011 Poland	Nonrandomized clinical trial 8 weeks	None	Supervised exercise sessions at outpatient clinic. No additional intervention specified as adjunct to home sessions.	Mobile device with preprogrammed exercise training sessions with audio and visual cues for training intensity and 3-lead ECG monitor. Data transmitted via mobile phone.	10 clinic supervised exercise sessions followed by 14 home exercise sessions with mobile application (3 sessions per week). (N=30)	24 clinic supervised exercise sessions (3 sessions per week). (N=32)	<i>Exercise Capacity:</i> 17.6±16.1% improvement mobile vs 11.5±35.9% control ($P>0.05$). <i>Risk Factors:</i> BP not significantly changed in either group. <i>Events:</i> not reported
Blasco ²² 2012 Spain	RCT 12 months	None	In person assessment. Lifestyle counseling. Intervention participants also supplied with blood pressure cuff, glucose and lipid meter as well as education on use.	Mobile phone with structured questionnaires for entry and transmission of blood pressure, heart rate, weight, glucose, and lipids. SMS messaging of recommendations.	Lifestyle counseling, mobile intervention, devices for home monitoring. (N=102)	Lifestyle counseling (N=101)	<i>Usability:</i> mHealth group completed 89% of entries. 5/102 dropped out due to difficulty with mHealth intervention. <i>Physical Activity:</i> 75% met goals in mHealth group vs 73% control. <i>Risk Factors:</i> mHealth group more likely to improve at least 1 risk factor for (RR 1.4, 95% CI 1.1 to 1.7) (primary outcome). mHealth group more likely to achieve goals for BP (62.1% vs 42.9%), hemoglobin A1c (86.4% vs 54.2%), and BMI (0.37 kg/m ² decrease vs 0.38 increase). No significant differences in smoking cessation, cholesterol, medication adherence. <i>Events:</i> 5 deaths in control group, 0 in mHealth group

6MWT indicates 6-minute walk test; CI, confidence interval; BMI, body mass index; BP, blood pressure; ECG, electrocardiogram; GPS, global positioning system; RCT, randomized clinical trial; RR, relative risk; SF-36, short form 36; SMS, short message service.

Table 3. Ongoing Studies of Mobile Technology for Cardiac Rehabilitation for Ischemic Heart Disease

Author/ Year/ Country	Design/ Duration	Theoretical Foundation	Non-mHealth Components	mHealth Components	Intervention	Control	Outcomes
Walters ²³ 2010 Australia	RCT 6 weeks (intensive) 6 months (follow-up)	None	In-person assessment. Individual goal setting with Mentor. Weekly mentoring sessions. Recommendation for walking-based exercise program.	Smartphone application with step counting, goal setting, diaries (weight, blood pressure, physical activity), visual feedback, text message reminders, educational videos, web portal. Subset will also have ECG and HR monitoring.	Smartphone application plus counseling (N=100). Smartphone application with ECG and HR monitoring plus counseling (N=15)	Outpatient center-based CR (N=100)	<i>Usability:</i> survey <i>Participation:</i> dropout rates <i>Physical Activity:</i> self-reported and objectively measured (primary outcome). <i>Exercise Capacity:</i> 6MWT <i>Risk Factors:</i> BMI, BP, smoking, alcohol, lipids, HbA1c, med adherence, Diet habits questionnaire <i>Health Status:</i> EQ-5D, Health Outcome Questionnaire, SAQ, Psychologic functioning <i>Cost:</i> facility, technology, return-to-work <i>Events:</i> hospitalizations and death
Maddison ²⁴ 2011 New Zealand	RCT 24 weeks	Self-efficacy Theory	In-person assessment and exercise prescription. Pedometer provided. Web portal for entry of physical activity, viewing videos, educational material.	SMS messages (personalized) for behavioral support to promote self-efficacy.	In-person assessment, personalized SMS messages and web portal. (N=85)	Referral to community- based CR. (N=85)	<i>Participation:</i> defined as at least 1 exercise session <i>Physical Activity:</i> IPAQ, Phone diary <i>Exercise Capacity:</i> Treadmill VO_{2max} (primary outcome), 6MWT. <i>Risk Factors:</i> BMI, waist and hip circumference, BP <i>Health Status:</i> self-efficacy, SF-36, EQ-5D <i>Cost:</i> program and medical <i>Events:</i> illness, signs and symptoms
Antypas ²⁵ 2012 Norway	Cluster RCT 1 year	Self-efficacy, Health Action Process Approach, Stages of Change	Completion of 4-week center-based CR program. Internet- based self- management program. Enhanced version includes tailoring of content and messages.	SMS reminder messages to fill out questionnaires.	Enhanced version of internet-based self management program. (N=8 clusters of 15 each)	Internet-based self management program. (N=8 clusters of 15 each)	<i>Usability:</i> log-in data, evaluation <i>Physical Activity:</i> IPAQ (primary outcome) <i>Risk Factors:</i> smoking, alcohol use <i>Health Status:</i> self-efficacy, Hospital Anxiety and Depression, social support, EQ-5D <i>Costs:</i> return-to-work
Alsaleh ²⁶ 2012 Jordan	RCT 6 months	Social Cognitive Theory, Self- efficacy Theory	In-person assessment and advice for CR. Physical activity diary.	Personalized SMS motivational messages (1/week × 3 months then 1/2 weeks × 3 months).	Personalized program and SMS messages. (N=71)	Advice from providers on physical activity. (N=85)	<i>Usability:</i> evaluation survey <i>Physical Activity:</i> IPAQ (primary outcome) <i>Health Status:</i> self-efficacy, Mac-New Heart Disease Questionnaire

6MWT, 6-minute walk test; BP, blood pressure; BMI, body mass index; CR, cardiac rehabilitation; ECG, electrocardiogram; EQ-5D, European quality of life—5 dimensions; HR, heart rate; IPAQ, International Physical Activity Questionnaire; RCT, randomized clinical trial; SAQ, Seattle Angina Questionnaire; SF-36, short form 36; SMS, short message service.

Table 4. Framework for Evaluating Mobile Applications for Cardiac Rehabilitation

1. Address core components of cardiac rehabilitation:
<ul style="list-style-type: none"> ● Patient assessment ● Exercise training ● Self management, may include: <ul style="list-style-type: none"> ○ Physical activity ○ Diet ○ Medication adherence ○ Smoking ● Psychosocial Support
2. Apply behavior change theory
3. Enable individual tailoring of features
4. Demonstrate high usability
5. Improve patient-centered outcomes:
<ul style="list-style-type: none"> ● Participation in cardiac rehabilitation ● Physical activity (energy expenditure) ● Exercise capacity ● Cardiovascular risk factors (nutrition, weight, blood pressure, cholesterol, diabetes, tobacco use) ● Patient-reported health status (symptoms, functional status, quality of life) ● Cost ● Cardiovascular events
6. Establish efficacy in a randomized clinical trial

outcomes.^{11,27–30} Based on data from the completed and ongoing studies of the use of mobile technology for cardiac rehabilitation, as well as the principles for establishing evidence for mobile health applications,^{27,30} we propose a framework for the development and evaluation of mobile applications for cardiac rehabilitation for patients with IHD (Table 4). The design of the mobile application should address the core components of cardiac rehabilitation, be based on behavior change theory, provide tailoring of the mobile application to the individual, and be highly usable. The evaluation of the mobile application should include rigorous study with a randomized clinical trial design comparing the mobile application to usual care and assessment of important patient-centered outcomes. In addition, the design and reporting of clinical studies of mobile applications for cardiac rehabilitation should adhere to the CONSORT (Consolidated Standards Of Reporting Trials) guidelines for mobile health interventions.³¹

Core Components of Cardiac Rehabilitation

The American Association of Cardiovascular and Pulmonary Rehabilitation specifies several key components that should

be included in a cardiac rehabilitation program (Table 1).^{2,3} However, the optimal components necessary to maximize the effectiveness of cardiac rehabilitation and simplicity of delivery are not entirely clear. Similar mortality benefits have been observed with education plus counseling, exercise training alone, and exercise training combined with additional interventions.^{4,32} A recent systematic review of alternative approaches to the delivery of cardiac rehabilitation concluded that (1) the most effective interventions combined individual patient risk factor management with psychosocial support, and (2) there was insufficient evidence to support interventions based solely on exercise training.³³ Naturally, health-care providers expect that technology-based cardiac rehabilitation will include similar components to traditional cardiac rehabilitation and occur in the context of supervision by a healthcare provider.³⁴ However, only one published study of mobile technology for cardiac rehabilitation has included components other than exercise training. Ongoing studies plan to evaluate a more comprehensive program of cardiac rehabilitation.

Based on these findings, we suggest that mobile technology-based interventions for cardiac rehabilitation should include individual patient risk factor assessment and management, exercise training, self-management of modifiable risk factors, and psychosocial support. Since the optimal combination of core components for mobile-delivered cardiac rehabilitation is unknown, this represents an important area for future research.

Theoretical Foundation for Behavior Change

Cardiac rehabilitation can be considered a behavior change intervention to promote healthy behaviors in patients with IHD. Interventions that are based on behavior change theory are more effective than those lacking a theoretical basis.^{35,36} To date, published studies of mobile cardiac rehabilitation have not specifically addressed behavior change strategies in their design. However, several of the ongoing studies specifically incorporate behavior change strategies, including short- and long-term goal setting,^{23,24,26} motivational messages and reminders,^{23,25,26} application of behavior change theories,^{24–26} and attention to promoting self-efficacy.^{24–26} Attention to principles from behavior change theories in the design of mobile interventions for cardiac rehabilitation may significantly increase the likelihood of success. In addition, mobile technology may provide an opportunity for delivering real-time cues to promote behavior change.¹¹

Individual Tailoring

Content development studies of mobile- and web-based cardiac rehabilitation support designing the intervention to

be tailored to the individual.^{34,37} Both web- and mobile-based systems offer the opportunity to remotely provide programmed feedback based on individually set preferences, short- and long-term goals, and personally tailored feedback from a cardiac rehabilitation provider. However, it appears that access and participation may be superior via a mobile platform.³⁸ All published and planned studies of the use of mobile technology for cardiac rehabilitation include some degree of tailoring the intervention to the individual, further highlighting the importance of tailoring in the design of mobile interventions for cardiac rehabilitation.

Usability

An easy-to-use interface is a desired feature of mobile applications for promoting physical activity.^{37,39} Ongoing studies suggest that mobile applications for cardiac rehabilitation can be highly usable, and that use may be promoted by automatic (preferably wireless) entry of data, such as objectively-measured physical activity.³⁸ Further study is needed on the features of mobile phone applications for cardiac rehabilitation that promote usability, including the need for integration of sensors for ECG monitoring, physical activity monitoring (via accelerometer and global positioning system [GPS]), and measurement of heart rate, blood pressure, and blood glucose. We propose that formal evaluation of the usability of the mobile application be conducted with user-testing and field studies to evaluate qualitative and quantitative measures of efficiency, effectiveness, and user satisfaction.^{40,41}

Patient-Centered Outcomes

Historically, the evaluation of cardiovascular disease interventions has focused on hard cardiovascular events such as death, myocardial infarction, heart failure, and stroke. However, it has become increasingly important to evaluate interventions in the context of patient-centered outcomes.^{42,43} Patient-reported health status includes symptoms, functional status, and health-related quality of life. These outcomes are influenced by physical, mental, and social health.⁴⁴ In patients with IHD, there are significant variations in health-related quality of life, even at similar severity of symptoms.⁴⁵ Thus, the impact of a mobile application on health outcomes must be examined at multiple levels, including participation in cardiac rehabilitation sessions,^{46,47} physical activity, exercise capacity, cardiovascular risk factors, patient-reported health status, costs, and clinical events.

Physical activity reduces risk of secondary cardiovascular events in patients with IHD.^{48,49} Although patient recall is a common method for evaluating physical activity, it is not as accurate as real-time reporting of physical activity.^{50,51} The

use of mobile technology offers a promising alternative to traditional recall-based physical activity questionnaires because physical activity can be reported in real-time through the mobile device. In one study, mobile-reported physical activity correlated with both objectively-measured physical activity and self-reported physical activity, but there was a large degree of variability in mobile-reported physical activity at similar levels of objectively-measured activity.⁵² Furthermore, mobile technology offers the possibility of interfacing with accelerometers, pedometers, and other wireless devices that track physical activity.

Exercise capacity is also protective against cardiovascular events in patients with IHD.^{53–57} Measurement of exercise capacity can be undertaken through a variety of methods, including cardiopulmonary exercise testing with expired gas measurement and treadmill exercise testing. The 6-minute walk test, a test of functional exercise capacity, predicts cardiovascular events similarly to treadmill exercise testing, and offers a simple and less resource-intensive method for measuring exercise capacity.⁵³ Using mobile technology, patients could conduct their own 6-minute walk test through device-based sensors (eg, GPS). Moreover, these measurements could be further integrated with other peripheral sensors (eg, measurement of ECG, heart rate, blood pressure, weight, blood glucose, and more), and with ecologic momentary assessment of behavioral and cognitive phenomena. Future research should include evaluation of the reliability and validity of sensors and ecologic momentary assessment for measuring health outcomes associated with mobile technology.

Cardiac rehabilitation is a cost-effective intervention for patients with IHD.⁵ It is unclear what the impact of the use of mobile technology will be on overall costs of care. Although mobile devices and wireless services are expensive, potential savings may include lower travel costs, fewer lost wages, and reduced rates of rehospitalization. Insights gained from the impact of mobile technology on health status may help tailor cardiac rehabilitation to the needs of the individual and ultimately decrease risk of secondary events in patients with IHD.

Efficacy in Randomized Clinical Trial

While observational studies and the analysis of observational data provide important insights about treatment effects, the gold standard for establishing efficacy remains the randomized clinical trial. Of the published studies on the use of mobile technology for cardiac rehabilitation, only 1 employed a randomized design, comparing the mobile intervention to standard risk factor counseling alone.²² Ongoing studies are planning randomized or cluster-randomized designs, which may provide evidence on the efficacy of mobile interventions for cardiac rehabilitation.^{23–26}

An important consideration in randomized study design is the selection of a comparison group. Since cardiac rehabilitation reduces mortality and is a guideline-recommended therapy, studies comparing the use of a mobile intervention to no intervention would pose ethical questions. However, standard practices and utilization of cardiac rehabilitation vary from country to country and region to region, creating a practical challenge for standardizing a comparison group. Thus, we recommend that studies of mobile interventions for cardiac rehabilitation be compared with best practices in the setting where the study is being conducted, preferably with referral to formal center-based or home-based cardiac rehabilitation, since these interventions have established efficacy.^{4,6}

Conclusions

New strategies for promoting participation in cardiac rehabilitation are desperately needed. Initial evidence supports the feasibility and acceptability of using mobile technology for cardiac rehabilitation in patients with IHD. Whether using mobile technology for cardiac rehabilitation can achieve its potential to improve access, increase participation, and ultimately improve outcomes in patients with IHD, remains to be seen.

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