Mobile-Application-Based Interventions for Patients With Hypertension and Ischemic Heart Disease: A Systematic Review

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ABSTRACT

Background: Hypertension and ischemic heart disease are major causes of adult mortality. Related interventions to manage these conditions are important to implement during long, symptom-free periods. The recent proliferation of smartphones has spawned numerous health interventions that rely on mobile applications.

Purpose: This systematic review was designed to summarize and analyze research on interventions using mobile applications for patients with hypertension and ischemic heart disease.

Methods: We searched for related studies published from January 2006 to August 2017 on MEDLINE, EMBASE, CINAHL, and three Korean databases. Seventeen studies were identified and evaluated against eligibility criteria that included a focus on patients with hypertension or ischemic heart disease and a discussion of the detailed effects of a mobile-app-based intervention. All of the identified studies were evaluated qualitatively using a methodology checklist.

Results: Twelve of the 17 studies were deemed as of acceptable quality according to the Scottish Intercollegiate Guideline Network quality assessment. According to the National Institutes of Health quality assessment tool, one article was of fair quality and four articles were of poor quality. Monitoring, education, and reminders were identified as application interventions. The effects of the app interventions were analyzed according to physiological factors, cognitive and behavioral factors, and psychological factors. Of the seven studies that measured blood pressure in patients with hypertension, five studies reported that the app-based interventions reduced blood pressure. Two of three studies showed a significant decrease of body mass index in patients with ischemic heart disease after the app-based interventions compared to the control group. Five of seven studies reported a significant change in medication adherence. Several studies showed different outcomes according to the disease, but the limited number of eligible studies was insufficient to demonstrate a conclusive effect.

Conclusions: To ensure the long-term effects of mobile-application-based interventions, healthcare professionals should consider the functions of mobile applications. Moreover, because the focus of these interventions may differ based on the nature of the disease, it is recommended that the composition of interventions be tailored to the specific disease.

KEY WORDS: mobile applications, hypertension, myocardial ischemia, systematic review.

Introduction

Cardiovascular disease is the leading cause of death among adults, contributing to about 31% of all deaths annually worldwide (World Health Organization, 2017). High blood pressure (BP) is the leading cause and risk factor of cardiovascular disease (Reboussin et al., 2018). Patients with ischemic heart disease (IHD) or hypertension experience longer symptom-free periods than symptomatic periods. Older male adults show particularly decreased awareness, self-management, and treatment compliance (Joseph et al., 2016). Self-management is essential to surviving the symptom-free period (Barnason et al., 2017; Souffront et al., 2016). Most patients with IHD or hypertension use medical services until their condition becomes severe and often have long intervals between visits. Patients with hypertension generally have high BP and high low-density lipoprotein (LDL) cholesterol and remain overweight or obese because they lack awareness of early symptoms and self-management techniques (Campbell et al., 2018; Souffront et al., 2016), such as BP and symptom monitoring and various lifestyle changes. Patients must be motivated to continue self-management (Reboussin et al., 2018), indicating the need for strategies to enhance participation and motivation.

Smartphone users have proliferated since 2007. In 2019, smartphone users were estimated to exceed 3.2 billion globally or approximately one third of the global population (Statista, 2019). Concomitant with this increase has been an increase in

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the number of health-related applications (apps). By 2018, around 50% of the 3.4 billion smartphone and tablet users were estimated to have downloaded health-related apps (Innovatemede tec, 2018).

Health-related mobile apps may promote self-management of chronic disease (Fu et al., 2017; Machado et al., 2016; Stuckey et al., 2017; Zhao et al., 2016). To be effective, health-related apps must contain accurate information that is developed and supervised by healthcare professionals (HCPs; Zhao et al., 2016). These apps can be used for numerous purposes, including the management of data and time, health records, and consultations; the reinforcement of self-monitoring and medication taking; data collection; clinical decision-making; patient monitoring; and education (Ventola, 2014). These apps help users save time and money by reducing the number of meetings between HCPs and patients and facilitate symptom-based decision-making by allowing HCPs to check on patient status information continually using user-entered data. Moreover, these apps enable interactive digital interventions to improve the treatment participation of patients (J. Lee et al., 2016; Ventola, 2014). Although self-management support via mobile apps, particularly those that rely on social networks and short message services (SMS), do raise concerns (Johnson et al., 2016), they provide solutions through personalized access.

**Methods**

**Aim**

Systematic literature reviews have been conducted on the topics of mobile-app-based interventions for mental health (Zhao et al., 2016), lower back pain (Machado et al., 2016), physical activities (Stuckey et al., 2017), diabetes (Brzan et al., 2016; Fu et al., 2017), and cardiovascular disease (Xie et al., 2017). However, the latter literature review study focused only on Chinese research and on patients with stroke, hypertension, or coronary artery disease. Therefore, this study was developed to contribute to evidence-based nursing by analyzing the contents and effects of mobile-app-based interventions in patients with hypertension or IHD in studies conducted in Korea or in other countries.

**Eligibility Criteria**

The review protocol was predefined according the Population, Intervention, Comparison, and Outcome framework using the PRISMA checklist. In this review, the population was limited to adult patients (≥ 18 years old) with hypertension or IHD; the interventions were mobile-app-based self-management apps accessed via smartphone or tablet platforms; the comparison was to a control intervention or no comparison; and the outcomes were physiological factors (e.g., BP, body mass index [BMI], and LDL), cognitive and behavioral factors (e.g., medication adherence, self-monitoring, physical activities, smoking cessation), psychological factors (e.g., quality of life [QoL], self-efficacy, stress), and satisfaction and acceptance of app. The exclusion criteria were articles that were not original articles (e.g., reviews, commentaries, or notes), studies conducted on nonhumans, studies not written in Korean or English, and qualitative studies.

**Data Sources and Search Methods**

MEDLINE, EMBASE, and CINAHL, three databases that met the Scottish Intercollegiate Guideline Network (SIGN) guidelines for literature searches, were searched for English language articles (SIGN, 2018). The search period was set for January 1, 2006, to August 31, 2017, and the keywords including “mobile app,” “smartphone,” “cell phone,” “mobile phone,” “cellular phone,” “portable app,” “mobile technology,” and “app” with “hypertension” and “myocardial ischemia” were applied in cross-searches of each of the databases to obtain optimal results. KoreaMed, Korea Education and Research Information Service, and Research Information Sharing Service were searched for Korean language articles using the terms “smartphone,” “mobile phone,” “SMS,” “application,” and “app.” Given the sensitivity and specificity of the search in these databases, terms were not cross-searched with “hypertension,” “myocardial ischemia,” or “heart muscle ischemia,” and no limits were set. All of the identified articles were extracted manually.

**Study Selection**

Data collection and screening were conducted independently by two researchers with over 3 years of clinical experience each. When their opinions conflicted, a third researcher joined the discussion until a consensus was reached.

**Quality Assessment**

Quality evaluations were performed on randomized controlled trials (RCTs) and nonrandomized controlled trials (NRCTs) using the SIGN study design and methodology algorithm (Shea et al., 2007). The other studies were evaluated by the U.S. National Institutes of Health quality tools (National Institutes of Health, 2018). Two researchers performed this evaluation, and their results were compared, with disagreements resolved via discussion (Shea et al., 2007; SIGN, 2018). Interventions and data collection conducted via an app (without direct contact with researchers) were considered blind, even when blinding was not described.

**Results**

Of the 3,570 articles (international: 574, Korean: 2,996) retrieved, 1,356 were excluded as duplicates, and a further 2,110 were excluded for not meeting the inclusion criteria. After reviewing the full texts of the remaining 104 articles, 87 were excluded for not meeting the eligibility criteria (Figure 1).

**Study Characteristics**

Seventeen articles were analyzed, nine of which were RCTs. The SIGN quality assessment revealed that 12 articles were acceptable (rating of at least 1+; Table 1). In terms of the National
Institutes of Health quality assessment, one article was identified as of fair quality and four articles were identified as of poor quality (see Table 2). Eight of the articles examined patients with hypertension (only hypertension, \(n=4\); hypertension and other disorders, \(n=4\)), and nine examined patients with IHD (only IHD, \(n=7\); IHD and others, \(n=2\)). The mean age of the participants in these articles ranged between 47.5 and 73.8 years.

**App Interventions**

Interventions were classified by actual application, intervention duration, and app function as “monitoring,” “education,” and “reminders” (Table 3). The apps monitored physiological measurements, symptoms, and performance status; delivered educational content; and provided reminders for medication and physiological measurements. Interventions ranged from 3 weeks to 12 months, with six articles using an intervention duration of 6 months and five articles using an intervention duration of 3 months (Table 3).

**Monitoring**

The apps used various methods of data sharing and feedback, depending on the data input method and level of HCP involvement in monitoring. The data input methods were manual or automatic, and input data included BP, heart rate, body weight, blood glucose, step count, physical activity, medication intake, symptoms, QoL, stress, smoking status, diet, and laboratory data. The scope of data sharing included the patient, HCP, data centers (platforms or portals), and family members. The feedback types included no feedback, automatic feedback generated by app or data center algorithms, and HCP feedback. In one article, data were selectively transferred to the HCP via either an algorithm or a central data center. HCP feedback could be delivered via SMS, telephone, or face-to-face (Table 3).

**Education**

The educational content included information on the disease, BP measurement methods, medications, diet, exercise, smoking cessation, weight control, and overall lifestyle patterns. This content was delivered mainly in written form. Most apps had some educational content. One app even provided tailored educational content based on user-inputted data and delivered it via SMS (Table 3).

**Reminders**

Reminders usually focused on medication, monitoring, or lifestyle modification and were delivered via the app, SMS, e-mail, or phone call (Table 3).
Effectiveness of App Interventions

The effectiveness of the intervention was evaluated in terms of physiological factors, cognitive and behavioral factors, and psychological factors. Studies also measured user satisfaction and acceptance of the app/device (Tables 4 and 5).

Physiological Factors

BP
Thirteen articles (seven RCTs, two NRCTs, and four before/after studies) measured BP. Seven and six focused on patients with hypertension and IHD, respectively. Of the former, five (two RCTs, one NRCT, two before/after studies) had positive effects on BP. One RCT reported that the mean change in systolic BP (SBP) and diastolic BP (DBP) decreased significantly more in the intervention group than the control group from baseline to 1 month (SBP \(-16.7\) mm Hg, \(p = .031\)), 4 months (after intervention \(-8\) mm Hg, \(p = .004\)), and 7 months (follow-up \(-9\) mm Hg, \(p = .006\); Patel et al., 2013) as well as decreased mean SBP and DBP between baseline and 8 weeks (SBP \(-7\) mm Hg, \(p = .008\) and DBP \(-4.9\) mm Hg, \(p = .002\); Bengtsson et al., 2016). In these studies, the users were able to immediately identify trends in BP (Albini et al., 2016; Bengtsson et al., 2016; Davidson et al., 2015; Or & Tao, 2016) or medication adherence (Patel et al., 2013). Two articles with apps that were designed to enable participants to immediately identify BP trends (Bloss et al., 2016) or medication adherence (Anglada-Martinez et al., 2016) did not identify a positive impact on BP.

Of the six articles (four RCTs, one NRCT, one before/after study) that focused on patients with IHD, two (one RCT, one NRCT) reported positive changes in submaximal rate pressure product (exercise capacity) after 12 weeks (SBP \(-28.24\) vs. \(-16.21\), \(p = .03\); Y. H. Lee et al., 2013) and the proportion of participants that reached a BP target (<149/90 mm Hg) after 12 months (62.1% vs. 42.9%, \(p < .012\); Blasco et al., 2016). However, these studies reported no group differences in SBP or DBP changes. Both of these studies included interventions featuring monitoring feedback from HCPs. However, another article that used this feedback did not identify a positive impact on BP (Karhula et al., 2015).

BMI
BMI was assessed in three RCTs (Blasco et al., 2012; Johnston et al., 2016; Widmer et al., 2017). In the two RCTs that focused on IHD, BMI decreased significantly more in patients than in controls after 3 months (1.6 vs. 0.3, \(p = .01\); Widmer et al.,...
2017) and 12 months (−0.37 vs. 0.38, \( p = .022 \); Blasco et al., 2012). One RCT reported a nonsignificant increase in BMI after 6 months compared with controls (−0.6 vs. −0.5, \( p = .366 \); Johnston et al., 2016). Participant age, intervention duration, and app components were not shown to affect these results.

**LDL**
One RCT found a decrease in LDL cholesterol, with LDL cholesterol decreasing significantly more in the app-based intervention group than the e-diary group (−1.8 vs. −1.0, \( p = .004 \)) after 6 months (Johnston et al., 2016). In two other RCTs, LDL cholesterol and/or triglycerides either decreased in both the intervention and control groups or were not compared between these groups (Blasco et al., 2012; Karhula et al., 2015). These interventions lasted for 8 weeks (Karhula et al., 2015), 6 months (Johnston et al., 2016), or 12 months (Blasco et al., 2012).

**Cognitive and Behavioral Factors**

**Medication adherence**
Seven articles examined medication adherence. Five of these reported a significant change and provided medication reminders (Anglada-Martínez et al., 2016; Johnston et al., 2016; Mertens et al., 2016; Moorhead et al., 2017; Patel et al., 2013). In one RCT, participants receiving SMS reminders and tailored education showed a lower nonadherence rate compared to patients receiving only SMS reminders (16.6 vs. 22.8, \( p = .025 \); Johnston et al., 2016). Another RCT showed that the use of acoustic pill reminders led to a greater increase in medication adherence during the intervention period than the use of paper diaries (\( p < .001 \); Mertens et al., 2016). In one before/after study, reminders and weekly motivational messages decreased missed medication days (vs. before the intervention; 3.5 vs. 0.4, \( p = .018 \)) and increased medication adherence (36.5% vs. 55.9%, \( p < .001 \); Anglada-Martínez et al., 2016). One article reported that the mean (SD) medication adherence for antihypertensive drugs increased significantly while using app (0.58 [0.20]) both compared with baseline (0.54 [0.27]) and after the intervention (0.46 [0.31]; \( F = 6.4, \ df = 2, \ p = .003 \); Patel et al., 2013). One study that examined an app for monitoring ingestion of sensor-enabled medicines found that medication adherence was higher when patients saw a reminder than when they did not (75% [SD = 18%] vs. 59% [SD = 24%]) and that this effect was more pronounced in participants with lower medication adherence (Moorhead et al., 2017). HCP recommendations were found to have no effect on medication adherence (Blasco et al., 2012).

**BP monitoring**
Two RCTs examined self-monitoring frequency, including BP measurement. In one RCT, participants who input daily BP data into the app and received medication reminders showed significantly greater adherence to daily BP monitoring compared to participants who recorded data on paper (\( p = .033 \)). Moreover, patients with hypertension showed stronger adherence than patients with other diseases (\( p = .036 \); Mertens et al., 2016). In the other RCT, BP monitoring frequency was similar in the intervention group (used an app that automatically recorded BP) and the control group (used paper; \( p = .460 \); Or & Tao, 2016). Finally, a before/after study revealed that BP monitoring decreased to 86% in the first intervention period and 77% in the second (Ammenwerth et al., 2015).
Physical activity

Five studies (four RCTs, one before/after study) assessed step counts (Ammenwerth et al., 2015; Martin et al., 2015) and physical activity (Blasco et al., 2012; Johnston et al., 2016; Widmer et al., 2017). In one RCT, the intervention group (provided a visible activity tracker and coaching messages informed by real-time activity) showed an increase in number of daily steps compared to those provided with a visible activity tracker only ($p < .001$) and those provided with nothing ($p < .001$; Martin et al., 2015). Three RCTs using, respectively, interventions with individualized automatic feedback (Johnston et al., 2016), automatic feedback for patient-entered values (Widmer et al., 2017), and feedback from HCP reviews (Blasco et al., 2012) reported no group differences in activity change. In addition, in one before/after study, the rate of achieving 3,000 steps per day decreased to 86% in the first intervention period and 73% in the second (Ammenwerth et al., 2015).

Smoking cessation

Three RCTs assessed smoking status (Blasco et al., 2012; Johnston et al., 2016; Widmer et al., 2017). Two reported no difference between the intervention and control groups in terms of smoking cessation rate (80% vs. 81%, $p = .964$; Blasco et al., 2012) or in terms of the number of quitters among active smokers (16 of 22 vs. 5 of 12, $p = .139$; Johnston et al., 2016). The remaining RCT did not detail postintervention results (Widmer et al., 2017). All of these articles focused on patients with IHD and provided feedback.
Psychological Factors

QoL, self-efficacy, anxiety, and stress

Seven and two articles assessed QoL and self-efficacy, respectively. Two articles (one RCT, one NRCT) reported increased QoL in an intervention group compared to a standard treatment group (Y. H. Lee et al., 2013; Widmer et al., 2017), whereas one before/after study reported an increase in QoL compared to baseline (p < .001; Ammenwerth et al., 2015). In one NRCT, self-efficacy increased more in an intervention group than in a standard treatment group (p = .011; Wolf et al., 2016), whereas in one RCT, no group difference was found (Bloss et al., 2016). Anxiety and stress were assessed in two articles, but neither showed significant changes (Blasco et al., 2012; Widmer et al., 2017). These articles had no similarities in terms of the duration or components of their respective interventions.

Satisfaction With and Acceptance of the App

Ten of the articles assessed user satisfaction and acceptance of the app/device. Acceptance and satisfaction rates were over 70% in five of the articles (Ammenwerth et al., 2015; Blasco et al., 2012; Davidson et al., 2015; Johnston et al., 2016; Patel et al., 2013). Two articles reported mean (SD) app satisfaction scores of 7.2 (2.7) out of 10 (Anglada-Martinez et al., 2016), 4.0 out of 5.0 for an activity tracker, and 3.8 out of 5.0 for a text message (Martin et al., 2015). In one study, technical affinity (i.e., positive attitude, excitement, and trust toward technology) was higher after an app-based intervention than after a paper-diary intervention (p = .002; Mertens et al., 2016). However, the average app usage rate decreased over time (Anglada-Martinez et al., 2016; Wolf et al., 2016).

Discussion

The contents and effectiveness of mobile-app-based interventions for patients with hypertension or IHD were assessed in this article. The app functions included “monitoring,” “education,” and “reminders,” which are similar to those suggested by HCPs (“data provision and education,” “patient monitoring,” and “time management”; Ventola, 2014). As management during the asymptomatic stages of hypertension and cardiovascular disease is critical, strategies employing medication reminders and BP monitoring have been emphasized (Barnason et al., 2017; Souffront et al., 2016). App data may be shared with patients, family members, central data centers, and HCPs. Sharing data with patients is useful in terms of improving patient motivation, whereas sharing data with HCPs helps them manage patient symptoms and make accurate clinical judgments (J. Lee et al., 2016; Rebourstin et al., 2018; Ventola, 2014). Providing data to family members may enhance patient self-management capabilities by promoting emotional support (Shawler et al., 2018). Although SMS and telephones have been used in the self-management of other chronic diseases, patient-centric, personalized feedback has been shown to provide the strongest benefit to intervention effects (Davies et al., 2012; Fukuoka et al., 2010; Maher et al., 2014). As feedback has shifted from being delivered primarily by HCPs to being generated by app algorithms, app developers have begun considering data sharing for HCPs and patients as an option for facilitating the economical use of these apps in early symptom management.

Physiological, cognitive–behavioral, and psychological factors as well as acceptance and satisfaction were the primary focuses of this study. App-based interventions were shown to reduce BP only in patients with hypertension. This finding may result from differences in the disease rather than the components or functions of the app-based intervention. Patients with hypertension primarily complain of increased BP, whereas patients with IHD primarily complain of chest pains. Hypertension is a risk factor that is present in the history of most patients with IHD and thus should be targeted for prevention (Agbor-Etag & Setaro, 2015). However, because of differences in interventions and research designs, the precise effects of these interventions are difficult to discern. However, in the articles that identified BP reductions in patients with hypertension, the apps focused on trends in either BP or medication adherence (Albini et al., 2016; Bengtsson et al., 2016; Davidson et al., 2015; Or & Tao, 2016; Patel et al., 2013). These findings are consistent with studies showing that the visualization of self-reported data motivates patients to adhere to treatment (Hallberg et al., 2015; Neubeck et al., 2015). However, Hallberg et al. (2015) suggested that treatment compliance varies with patient ability to understand graphs. This is supported by findings from two studies in which BP levels did not abate despite the use of graphically presented self-report data (Anglada-Martinez et al., 2016; Bloss et al., 2016). Therefore, to motivate patients to follow their treatments, graphs should be easy to understand. Furthermore, using graphs for counseling may improve patient adherence.

Feedback from HCPs was a common component in interventions that improved BP outcomes in patients with IHD (Blasco et al., 2012; Y. H. Lee et al., 2013). Thangada et al. (2018) found that a mobile-app-based intervention containing additional HCP feedback improved BP outcomes and suggested that HCP feedback may help patients understand data trends and promote self-management. Neubeck et al. (2015) further suggested that feedback, including personal goal setting and tailored information, is useful for symptom management. However, Karhula et al. (2015) found that this type of feedback did not have a positive impact on BP. They measured this in terms of BP change, whereas the previous two studies focused on exercise capacity using BP and the achievement rate of BP targets. Thus, researchers should develop tools that more accurately measure intervention effects in patients with IHD who desire to control rather than reduce their BP.

BMI was assessed in three of the studies on patients with IHD (Blasco et al., 2012; Johnston et al., 2016; Widmer et al., 2017). BMI decreased in two studies and remained the same in one study (Johnston et al., 2016). Effective weight control interventions should focus on diet, physical activity, behavior therapy, and emotional support (Ramage et al., 2014). Furthermore,
Table 3
Components of Mobile-Application-Based Interventions for Patients With Hypertension and Ischemic Heart Disease

| No. | Authors (Year)          | Disease                    | Application                                                   | Duration                  |
|-----|-------------------------|----------------------------|---------------------------------------------------------------|---------------------------|
| 1.  | Blasco et al. (2012)    | ACS                        | Wireless app                                                  | 12 months                 |
| 2.  | Lee et al. (2013)       | ACS                        | Wireless monitoring (HeartCall)                               | 4–6 weeks                 |
| 3.  | Patel et al. (2013)     | HTN                        | Pill phone application                                        | 10 months (activation phase: 3 months) |
| 4.  | Ammenwerth et al. (2015)| ACS                        | MyCor health diary app                                        | 4.5 months                |
| 5.  | Davidson et al. (2015)  | HTN                        | App, bluetooth-BP monitor                                     | 6 months                  |
| 6.  | Karhula et al. (2015)   | DM, heart disease          | Personal health record app                                    | 8 weeks                   |
| 7.  | Martin et al. (2015)    | DM, CHD                    | Fitbug Orb                                                   | Phase I: 2–3 weeks Phase II: 4–5 weeks |
| 8.  | Albini et al. (2016)    | HTN                        | Misuriamo platform/Eurohypertension app                       | 3 months                  |
| 9.  | Anglada-Martinez et al. (2016) | HTN, dyslipidemia, HF, HIV | Medplan platform/mobile phone app                             | 6 months                  |
| 10. | Bengtsson et al. (2016) | HTN                        | Circadian questions                                           | 8 weeks                   |
| 11. | Bloss et al. (2016)     | HTN, DM, arrhythmia        | Mobile devices+ HealthyCircles                                | 6 months                  |
| 12. | Johnston et al. (2016)  | MI                         | Web-based app                                                 | 6 months                  |
| 13. | Mertens et al. (2016)   | ACS or MI                  | Medication Plan app                                           | 3 and 6 months            |
| 14. | Or & Tao (2016)         | DM, HTN                    | Tablet computer-based disease self-monitoring system          | 3 months                  |
| 15. | Wolf et al. (2016)      | ACS                        | eHealth diary, symptom-tracking tool                          | 6 months                  |
| 16. | Moorhead et al. (2017)  | HTN, DM                    | App, provider portal                                          | 3 months                  |
| 17. | Widmer et al. (2017)    | ACS                        | App or Web-based portal                                       | 3 months                  |

Note. ACS = acute coronary syndrome; app = application; BP = blood pressure; BW = body weight; HbA1c = hemoglobin A1c; HCP = healthcare professional; SMS = short message services; HR = heart rate; HTN = hypertension; Pts = patients; DM = diabetes mellitus; CHD = coronary heart disease; HF = heart failure; MI = myocardial infarction.
| Data Entry | Scope of Data Sharing | Type of Feedback | Contents | Method | Purpose | Delivery Type |
|------------|-----------------------|------------------|----------|--------|---------|---------------|
| Manual (BP, BW, cholesterol, glucose, HbA1c) | Provider portal/HCP | Feedback from HCP review | — | — | Recommendations | SMS |
| Automatic (HR) | Provider portal/HCP | Feedback from HCP review | Risk factors for heart disease, diet, exercise | Face to face | Counseling | Call (once weekly) |
| Manual (medication taking) | Pts | None | — | — | Medication | App message |
| Manual (BP, HR, BW, step count, drug intake, glucose) | Provider portal | Automatic feedback | Medication, lifestyle | — | Individual goals | App message (once weekly) |
| Automatic (BP) | Pts | Automatic feedback | — | — | Medication, BP monitor, motivation | SMS |
| Manual and (glucose, BW, step count) automatic (BP) | Pts/provider portal/HCP | Feedback from HCP review | Self-management guide | Text | — | — |
| Automatic (step count, activity time) | Pts | Automatic feedback | Habit formation | App | Positive reinforcement | SMS (3 times/day) |
| Manual (BP) | Pts or caregiver/provider portal/HCP | Feedback from HCP review | Drug information/lifestyle | App | Medication | App alarm/e-mail |
| Manual (medication) | Pts or caregiver/provider portal/HCP | Feedback from HCP review | Drug information/lifestyle | App | Medication | App alarm/Weekly motivational messages |
| Automatic (BP, HR), manual (drug intake) | Pts/provider portal/HCP | Automatic feedback | Well-being, symptoms, lifestyle, medication | Questions | Lifestyle change | Weekly motivational messages |
| Manual (BP, glucose, arrhythmia) | Pts/HCP | Feedback from HCP review | Disease, health behavior | App | Monitoring schedule | e-mail |
| Manual (drug adherence e-diary) | Pts | Automatic feedback | Drug adherence, e-diary, exercise, BW, smoking | Text | Medication | SMS (twice/day) |
| Manual (BP, medication intake) | Pts | None | — | — | Medication | App alarm |
| Automatic (glucose, BP) | Pts/family | None | Measurement of glucose and BP/diet, exercise | Video | — | — |
| Manual (fatigue, symptom) and automatic (activity) | Pts | None | — | — | — | — |
| Automatic (medication, activity, rest) | Pts, provider portal | None | — | — | Medication | App message |
| Manual (BP, BW, lipid, glucose) | Pts | Automatic feedback | — | — | — | — |
| No. | Authors (Year)/Country | Study Design | Population | Intervention | Comparator |
|-----|------------------------|--------------|------------|--------------|------------|
| 1.  | Blasco et al. (2012)/Spain | RCT | ACS 203 EG: 102 (DM 30, 60.6 yr, M/F 83/19), CG: 101 (DM 26, 61 yr, M/F 80/21) | Structured questionnaire | Usual care |
| 2.  | Lee et al. (2013)/Korea | NRCT | 55 ACS undergoing PCI: EG 26 (54.3 yr, M/F 22/4), CG 29 (57.8 yr, M/F 22/7) | Wireless monitoring (HeartCall) | Usual care |
| 5.  | Davidson et al. (2015)/United States | RCT | HTN EG 18 (47.5 ± 11.8 yr, M/F 7/11), CG 20 (48.5 ± 11.3 yr, M/F 8/12) | Software application, Bluetooth-accessible BP monitor | Standard care |
| 6.  | Karhula et al. (2015)/Finland | RCT | Heart disease 246 (69.1 yr, M/F 178/269, CG/EG 79/190), DM 225 (66.2 yr, M/F 129/250, CG/EG 70/180) | Mobile personal health record app | Standard care |
| 7.  | Martin et al. (2015)/United States | RCT | • Total 48  • Phase I (n = 48): unblind 32, blind 16  • Phase II: text 16 (55 ± 8 yr, M/F 8/8, DM 2, CHD 2), no text 16 (58 ± 8 yr, M/F 9/7, DM 5, CHD 5), blind 16 | Fitbug Orb | No text |
| 8.  | Albiniet al. (2016)/Italy | NRCT | HTN 691 EG 303 (57.9 ± 11.3 yr, M/F180/123), CG 298 (66.9 ± 11.5 yr, M/F 188/110) | Misuriamo platform/ Eurohypertension app | Educational modules |
| Outcome | Measurement Method | Physiological | Cognitive and Behavioral | Psychosocial | Satisfaction and Acceptance of App |
|---------|-------------------|---------------|------------------------|--------------|-----------------------------------|
| BP: ND  | Measurement: baseline, 12 mo | Achievement for goal (<140/90 mm Hg) in EG vs. CG: in BP (62.1% vs. 42.9%, \( p = .012 \)) | Medication adherence: ND | QoL, anxiety: ND | Adherence to protocol: 89.2 ± 16.0% |
| BMI: change of BMI in EG vs. in CG (−0.37 vs. 0.38, \( p = .022 \)) | LDLS: ND | Physical activity: ND |  |
| Achievement for goal (HbA1c < 7%) (86.4% vs. 54.2%, \( p = .018 \)) among DM | LDL: ND | Achievement for smoking cessation: ND |  |
| Change in EG vs. CG: |  |
| RPPsubmax (−28.24 vs. −16.21 bpm·mm Hg, \( p = .013 \)), RPEsubmax (\( p = .018 \)), METs (\( p = .012 \)), ETmax (\( p = .012 \)) | QoL change: EG vs. CG (4.8 vs. 0.9, \( p = .022 \)) |  |
| BP control: 70.6% of EG vs. 15.8% of CG (<140/90 mm Hg) at 1 mo (\( p < .001 \)), 94.4% of EG vs. 41.2% of CG at 6 mo (\( p < .003 \)) |  |
| Clinical outcome (SBP, DBP, LDL, BW, waist circumference) of heart disease: ND between EG and CG | Medication adherence: 92 ± 0.09 in EG | Feasibility: 88.4% in 6 mo |
| Within EG: waist circumference ↓ (\( p = .02 \)), SBP↓ (\( p < .001 \)), LDL↓ (\( p < .001 \)) | BP Adherence (every 3 days): 86.2 ± 6% in EG |  |
| Within CG: LDL↓ (\( p < .001 \)), SBP↓ (\( p < .001 \)) | QoL: ND | Duration of coaching call: heart disease higher than DM (\( p = .004 \)) |
| Mean change of step count |  |
| Phase I: ND | Satisfaction score: for activity tracker 4.0 of 5.0, for text messages 3.8 of 5.0 |
| Phase II: text higher than no text (2534, 95% CI [1318, 3750], \( p < .001 \)), blind (3376, 95% CI [1951, 4801], \( p < .001 \)) |  |
| Office BP control: 40.0% in CG vs. 72.3% in EG at 6 mo F/U (\( p < .0001 \)) |  |
| At same time Home BP control in EG: 87.5% |  |
Table 4
The Effects of Mobile-Application-Based Interventions for Patients With Hypertension and Ischemic Heart Disease in RCTs and NRCTs, Continued

| No. | Authors (Year)/Country | Study Design | Population                     | Intervention                          | Comparator                                                                 |
|-----|------------------------|--------------|---------------------------------|---------------------------------------|---------------------------------------------------------------------------|
| 11. | Bloss et al. (2016)/United States | RCT          | EG 75 (56 ± 9 yr, HTN 67, NIDDM 10, IDDM 10, arrhythmia 10) CG 85 (55 ± 9.8 yr, HTN 71, NIDDM 17, IDDM 10, arrhythmia 19) | Mobile devices (BP, blood glucose, ECG) + Healthy Circles | usual care                                                               |
| 12. | Johnston et al. (2016)/Sweden | RCT          | MI 186 (58 yr, M/F 150/36) EG 85 (56.8 yr) CG 77 (58.4 yr) | Web-based app | Simplified e-diary without secondary education and medication reminder |
| 13. | Mertens et al. (2016)/Germany | RCT          | ACS or MI 24 (73.8 yr, M/F 12/12) | Medication Plan app | Pen and paper diary                                                      |
| 14. | Or & Tao (2016)/Hong Kong | RCT          | EG 33 (HTN 19, DM + HTN 14, 69.3 ± 9.7 yr, M/F 14/19) CG 30 (DM 2, HTN 19, DM + HTN 9,69.7 ± 10.2 yr, M/F 6/14) | Tablet computer-based disease self-monitoring system | Paper diary                                                               |
| 15. | Wolf et al. (2016)/Sweden | NRCT         | ACS • CG 106 (61.3 ± 8.9 yr, M/F 72/32) • PCC + eHealth 37 (59.8 ± 10.1 yr, M/F 30/7) • PCC no eHealth 57 (60.9 ± 8.7 yr, M/F 41) | eHealth diary + symptom-tracking tool | Drug adherence e-diary without the secondary prevention |
| 17. | Widmer et al. (2017)/United States | RCT          | ACS 71 EG (CG + DHI) 37 (62.5 ± 10.7 yr, M/F 29/8), CG 34 (63.6 ± 10.9 yr, M/F 29/10) | App or Web-based portal | Standard Phase II                                                         |

Note. RCT = randomized controlled trial; NRCT = nonrandomized controlled trial; ACS = acute coronary syndrome; EG = intervention group; CG = control group; BP = blood pressure; BMI = body mass index; QoL = quality of life; LDL = low-density lipoprotein; HbA1c = hemoglobin A1c; ND = no differences; DM = diabetes mellitus; PCI = percutaneous coronary intervention; M = male; F = female; yr = year; wk = week; mo = month; SBP = systolic blood pressure; DBP = diastolic blood pressure; F/U = follow-up; HTN = hypertension; NIDDM = non-insulin-dependent diabetes mellitus; IDDM = insulin dependent diabetes mellitus; ER = emergency room; HI = health insurance; pt = patient; MI = myocardial infarction; FBS = fasting blood glucose; ↓ means decreased.
| Outcome | Measurement Method | Physiological | Cognitive and Behavioral | Psychosocial | Satisfaction and Acceptance of App |
|---------|--------------------|---------------|-------------------------|--------------|----------------------------------|
| SBP in HTN, HbA1c in DM: ND | Measurement: baseline, 3 mo, 6 mo | DBP in HTN: 3.6 mm Hg in EG (p = .035), 6.1 mm Hg in CG (p = .004), ND between groups | Nonadherence score: EG lower than CG (16.6 vs. 22.8, p = .025) | Self-efficacy or pts activation: ND | Device usability score: EG higher than CG at end (87.3 vs. 78.1, p = .001) pts satisfaction: 97.5% in EG |
| SBP, BMI: ND | Measurement: baseline, 1st (baseline), 2nd (6–10 wk), 3rd (6 mo) visit | LDL: EG lower than CG (−1.8 vs. −1.0, p = .004) | Smoking, physical activity: ND | QoL: ND | Technical affinity: tablet vs. paper (p = .002) |
| SBP in HTN, HTN + DM: ↓ from baseline to 1 mo (p < .001) to 3 mo (p = .043) | Measurement: baseline, 1 mo, 2 mo, 3 mo | DBP in HTN, HTN + DM: ↓ from baseline to 1 mo (p < .001) to 2 mo (p = .028) to 3 mo (ND) | Frequency of self-monitoring: ND | HTN knowledge: ND | |
| FBS, HbA1c in DM, HTN + DM: ND | Measurement: baseline, 4 wk, 8 wk, 6 mo | BW: −5.1 ± 6.5 vs. −0.8 ± 3.8 kg (EG vs. CG, p = .02) | Min of physical activity: ND | Use of time of eHealth tool: 38 ± 33 times (range 1–118) during first 8 wk, 64 ± 104 times (range 1–597) over 6-mo period |
| BW: −5.1 ± 6.5 vs. −0.8 ± 3.8 kg (EG vs. CG, p = .02) | Measurement: baseline, 3 mo, 6 mo | BMI: −1.6 ± 1.9 vs. −0.3 ± 1.7 (EG vs. CG, p = .01) | Smoking: cannot identify | QoL: 7.2 ± 1.3 in EG vs. 2.4 ± 1.6 in CG (p = .03) | |
| Waist circumference: −8.3 ± 3.1 vs. 1.1 ± 4.1 cm (EG vs. CG; p = .01) | Outcome (baseline, 3 mo): lab (FBS, lipid, glucose), BP, BW, health behavior (diet, physical activity, QoL, stress, smoking), major adverse cardiac event | SBP, DBP, glucose, lipids, major adverse cardiac event: ND | Stress: ND | |
### Table 5
The Effects of Mobile-Application-Based Interventions for Patients With Hypertension and Ischemic Heart Disease in Single-Arm Studies

| No. | Authors (Year)/Country          | Study Design                  | Population                                                                 | Intervention          | Comparator  |
|-----|---------------------------------|-------------------------------|---------------------------------------------------------------------------|------------------------|-------------|
| 3.  | Patel et al. (2013)/United States | Before/after study            | HTN 50 (63.0 ± 8.7 yr)                                                    | Pill Phone app        | None        |
| 4.  | Ammenwerth et al. (2015)/Austria | Before/after study            | ACS 25 (63 yr, M/F 25/1)                                                  | MyCor health diary app| None        |
| 9.  | Anglada-Martínez et al. (2016)/Spain | Before/after study          | Total 42 (56 ± 8 yr, HTN 17, dyslipidemia 12, HTN + dyslipidemia 5, HIV 8)| Medplan platform/mobile phone app | None        |
| 10. | Bengtsson et al. (2016)/Sweden  | Before/after study            | HTN 51 (59.5 yr, M/F 26/24)                                               | Circadian Questions   | None        |
| 16. | Moorhead et al. (2017)/United States | Interrupted time series      | HTN, DM dose reminder efficacy 57 (58 ± 10.5 yr, M/F 28/29) dose reminder safe 74 (57 ± 9.9 yr, M/F 34/40) | Digital Health        | None        |

Note. HTN = hypertension; BP = blood pressure; pt = patient; SBP = systolic blood pressure; DBP = diastolic blood pressure; ND = no differences; ACS = acute coronary syndrome; yr = year; wk = week; mo = month; M = male; F = female; F/U = follow-up; BW = body weight; HR = heart rate; QoL = quality of life; TG = triglyceride; ↓ means decreased.
| Outcome | Measurement Method | Physiological | Cognitive and Behavioral | Psychosocial | Satisfaction and Acceptance of App |
|---------|--------------------|---------------|-------------------------|--------------|-----------------------------------|
| • Measurement: baseline (Visit 1), pre-use (Visit 2), use (Visit 3), off (Visit 4) | • SBP compared with baseline ($F = 4.4$, $p = .007$); ↓ Visit 1 ($p = .031$), ↓ Visit 2 ($p = .004$), ↓ Visit 4 ($p = .006$) | • Adherence (pharmacy refill rate): Visit 1 $= 0.54 \pm 0.27$, Visit 3 $= 0.58 \pm 0.20$, Visit 4 $= 0.46 \pm 0.31$ ($F = 6.4, df = 2, p = .003$) | - | • satisfaction of medication reminder app at final: 96% |
| • Outcome: BP, adherence with HTN medication (pharmacy refill rate), adherence with HTN medication (questionnaire; app during intervention period, Visit 3), satisfaction, pt-specific usage of Pill Phone | • DBP: ND | • Adherence (questionnaire): Visit 4 higher than Visit 1 ($p < .001$) | • QoL: pre-5.5, post 6.3 ($p < .001$) | • Pt-specific Usage of Pill Phone: ND |
| • Measurement: baseline, Phase 1 (telemonitoring, 4 wk), 1st F/U (4 wk), Interim phase (12 wk), Phase 2 (Telemonitoring, 2 wk), 2nd F/U | • BP, HR: ND | • Adherence to daily measurements: 86% (Phase 1), 77% (Phase 2) | • QoL: ND | • Device satisfaction: 72% (very or partly confident) |
| • Outcome: system quality, information quality, service quality, user satisfaction, intention to use, net benefit, health diary data (BW, BP, footsteps), QoL | • SBP/DBP in HTN, HTN+Dyslipidemia: ND | • Adherence: Pharmacy refills: ND | | |
| • Measurement: baseline, 3 mo, 6 mo | • Cholesterol and TG in dyslipidemia: ND | • SMAQ: pre 36.5%, post 55.9% ($p < .001$) | | |
| • Outcome: QoL, medication adherence (Simplified Medication Adherence Questionnaire, SMAQ), medication adherence, health outcomes (BP in HTN, cholesterol and TG in dyslipidemia), healthcare resources visit | | • Number of days with missing doses: pre 3.5, post 0.4 ($p = .018$) | | |
| • Measurement: baseline, 8 wk | • Mean SBP/DBP between baseline and 8 wk: SBP $7 \text{ mm Hg} \downarrow$ ($p = .008$), DBP $4.9 \text{ mm Hg} \downarrow$ ($p = .002$) | • Adherence: Pharmacy refills: ND | • QoL: ND | • Satisfaction: satisfaction score: 7.2 $\pm$ 2.7 in pts, recommend app: 71.4%, wanted to continue: 88.1% |
| • Outcome: BP | | • SMAQ: pre 36.5%, post 55.9% ($p < .001$) | | • usability: registered in app: overall 58.4%, 4 mo 60.2%, 6 mo 56.6% ($p < .001$) |
| • Measurement: continuous | • Mean difference in medication adherence after seeing and not seeing the medication dose reminder: $15.6 \pm 15.6\%$ (75 $\pm$ 18% vs. 59 $\pm$ 24%) | • Number of days with missing doses: pre 3.5, post 0.4 ($p = .018$) | | |
patients’ general characteristics and diseases should be considered. However, some studies (Blasco et al., 2012; Widmer et al., 2017) included weight measurement without education, and even when education was included, the interventions were not multidisciplinary.

In asymptomatic patients with cardiovascular disease, medication is important for preventing disease progression (Kjeldsen et al., 2014). Acknowledging this, several of the articles in this systematic review assessed medication adherence. Five of the articles (Anglada-Martinez et al., 2016; Johnston et al., 2016; Mertens et al., 2016; Moorhead et al., 2017; Patel et al., 2013) investigated apps with medication reminders, and although different measurement methods were used, all five reported significant results. These results are consistent with a previous study (Thakkar et al., 2016). However, medication adherence was higher in patients with IHD than in patients with hypertension. This may be because IHD is more severe than hypertension, as medication adherence is influenced by patient characteristics, disease severity, medication regimen, HCP and healthcare system characteristics, and socioeconomic factors (S. Q. Lee et al., 2018). Although app-based medication reminders are more effective and user-friendly for medication adherence according to cognitive behavioral theory, there may be weakened adherence when used over longer durations, as was previously observed in relation to the acceptance rate of health-related apps (Hincapie et al., 2019). Medication nonadherence is associated with the health system, risk factors of cardiovascular complications, age, therapy complexity, length of medical history, and socioeconomic status (Ho et al., 2009; Bokhour et al., 2006). Thus, factors related to medication adherence should be considered when using reminders to improve adherence (Barnason et al., 2017; S. Q. Lee et al., 2018).

Increased physical activity was found in one of the articles (Martin et al., 2015). Patients in that study were provided with education on habit formation, and positive reinforcement based on the cognitive behavioral model was provided three times per week to help sustain positive behavioral changes. Self-awareness of the management of chronic asymptomatic diseases is generally low, causing physical activity or self-monitoring to decline over time (Ammenwerth et al., 2015; Campbell et al., 2018; Zhao et al., 2016). Thus, strategies and attractive apps must be developed to ensure long-term self-management in patients with hypertension and cardiovascular disease (Brzan et al., 2016; Fu et al., 2017).

Two RCTs for IHD identified no positive effect of app-based interventions on smoking cessation. These interventions lasted for 6 months (Johnston et al., 2016) and 12 months (Blasco et al., 2012) and focused on participants with mean ages of 58 (Johnston et al., 2016) and 60.6 years (Blasco et al., 2012). In a previous systematic review, mobile-phone-based interventions may be effective in inducing smoking cessation only after 6 months (Whittaker et al., 2016). The lack of an effect found in this systematic review is likely due to participants being older and having smoked for longer periods of time than the participants of studies covered in the previous review (mean age range: 18.2–44.8 years). Intention to quit and nicotine dependence are strong predictors of successful cessation, and intention to quit among older adults is lower than among younger individuals (Siahpush et al., 2006). A qualitative study found that most elderly smokers, though aware of the health risks of smoking, believed that the damage had already been done and that little benefit would be gained from quitting (Kerr et al., 2006). Thus, smoking cessation strategies tailored to older patients with hypertension or IHD should be implemented.

As for the psychological factors, QoL increased in three of the studies on patients with IHD (Ammenwerth et al., 2015; Y. H. Lee et al., 2013; Widmer et al., 2017). The QoL questionnaires focused on the emotional, social, and physical domains (e.g., chest pain), indicating that physical symptoms as well as psychosocial factors improved over time. Thus, interventions should focus on total relief for patients with IHD and consider using holistic approaches that involve the emotional, social, and physical domains. QoL may be improved through self-management due to monitoring and behavioral change (Johnson et al., 2016; Zhao et al., 2016). Therefore, overall, mobile apps may be effective in improving psychological factors.

Some of the studies found that the acceptance rates of apps were higher than those of paper diaries, although app acceptance rates decreased over time (Anglada-Martinez et al., 2016; Wolf et al., 2016). The decline in app acceptance may reflect users’ app-engagement experiences, app technical functionality, ease of app use, and/or app design features (Anderson et al., 2016; Suh et al., 2015). These results suggest that additional strategies to sustain the intervention effects must be developed (Brzan et al., 2016; Fu et al., 2017).

Before 2000, team-based interventions were frequently used to improve self-management (Whelton et al., 2002). Recently, online health communication has rapidly increased as a result of smartphones and the Internet (Innovatemedtec, 2018; Statista, 2019). The effect of interventions that use the Internet or apps may vary based on the reliability of the data and user characteristics (Paige et al., 2017). Therefore, to maintain self-management among patients with hypertension or IHD, apps may be designed to incorporate online meeting functions (based on the user’s characteristics or needs), patient-to-patient encouragement or reinforcement, patient-to-HCP online communication, and more-reliable educational content.

This systematic review showed that mobile apps have inconsistent effects on self-management in patients with hypertension and IHD. Similar to studies evaluating mobile apps for other chronic diseases, this inconsistency may result from differences in content, attractiveness, user convenience, suitability of educational content, user characteristics (e.g., culture, age, gender), and intervention duration (Brzan et al., 2016; Fu et al., 2017; Machado et al., 2016; Stuckey et al., 2017; Zhao et al., 2016). Because most of the OF app-based interventions revealed diminishing effects over time, strategies such as providing accurate information, attractive reminders, and individualized content are necessary to promote their sustained effectiveness (Brzan et al., 2016; Fu et al., 2017).
Strengths and Limitations
All of the articles in this systematic review study were published in English only. Moreover, some were low-quality, single-arm studies. However, by including all study types regardless of quality, this study offers a broader review of interventions. The findings of this study indicate that interventions should selectively apply app functions based on patient characteristics in order to improve app accessibility, reduce costs, and promote self-management.

Conclusions
Mobile apps may provide an effective means to self-manage hypertension and IHD. Apps may be designed to provide educational content and individualized reinforcement strategies, including self-monitoring, feedback, and reminder functions, to promote long-term self-management. HCPs may use app-collected data to improve the accuracy of decision-making and to promote early symptom management, which will benefit patients who cannot regularly visit the hospital or clinic. Apps may provide an effective tool to improve the self-management efficacy of patients with hypertension or IHD, which will reduce complications and improve survival and QoL.

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