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HYPERTENSION (DS GELLER AND DL COHEN, SECTION EDITORS)

The Emerging Role of Mobile-Health Applications in the Management of Hypertension

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Abstract

Purpose of Review Mobile-health technology, frequently referred to as m-health, encompasses smartphone, tablet, or personal computer use in the management of chronic disease. There has been a rise in the number of commercially available smartphone applications and website-based platforms which claim to help patients manage hypertension. Very little research has been performed confirming whether or not use of these applications results in improved blood pressure (BP) outcomes. In this paper, we review existing literature on m-health systems and how m-health can affect hypertension management.

Recent Findings M-health systems help patients manage hypertension in the following ways: (1) setting alarms and reminders for patients to take their medications, (2) linking patients' BP reports to their electronic medical record for their physicians to review, (3) providing feedback to patients about their BP trends, and (4) functioning as point-of-care BP sensors. M-health applications with alarms and reminders can increase medication compliance while applications that share ambulatory BP data with patients' physicians can foster improved patient-physician dialog. However, the most influential tool for achieving positive BP outcomes appears to be patient-directed feedback about BP trends.

Summary A large number of commercially available m-health applications may facilitate self-management of hypertension by enhancing medication adherence, maintaining a log of blood pressure measurements, and facilitating physician-patient communication. A small number of applications function as BP sensors, thereby transforming the smartphone into a medical device. Such BP sensors often generate unreliable recordings. Patients must be cautioned regarding the use of smartphones for BP measurement at least until these applications have been more extensively validated.

Keywords Mobile-health · Smartphone · Hypertension and outcomes research

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Introduction

Hypertension is a prevalent and growing public health problem in the USA and worldwide. According to recent estimates, over one in three Americans and 1 billion people worldwide are hypertensive [1, 2]. Recent data from the 2011–2014 National Health and Nutritional Examination Survey (NHANES) suggest that among patients with prevalent hypertension, nearly half have blood pressures (BP) that remain uncontrolled [3]. These data also found significant sex and racial disparities in hypertension burden and control with higher prevalence and worse BP control among blacks compared with whites and among males compared with females [3]. About 20% of adults with hypertension are unaware of the diagnosis, and among those who are aware, BP remains uncontrolled after three or more antihypertensives in 13.7% of adults [1, 4]. These data shed light on the opportunities for improvement in hypertension diagnosis, patient awareness, and control rates in all populations and especially those with limited access to health care.

Self-management of hypertension can play an important role in promoting BP control in hypertensive patients. Some components of self-management that have been shown to have impact BP control include ambulatory BP monitoring, lifestyle modifications, and medication adherence [5–7]. In a recent clinical trial, patients assigned to self-management achieved significantly lower BP compared with those assigned to usual care alone [8].

Recent large surveys have shown that a significant proportion of US adults rely on Internet- and smartphone-based resources for self-management of chronic diseases such as hypertension. In a survey conducted by the Pew Research Organization, rates of smartphone ownership have increased sharply in recent years and stood at 77% in 2016 [9]. Internet penetration rates have also steadily continued to increase with 88% of US adults using the Internet in 2016 [10]. Smartphone adoption is rapidly expanding in low- to middle-income countries with a median 37% smartphone ownership in 2015 in these countries [11]. Up to 17% of Americans between the ages of 18–29 rely exclusively on smartphones for internet access, and do not have a home broadband internet provider [9]. Such data suggest that smartphones are becoming an integral part of people's lives, serving many purposes such as scheduling, booking appointments, and managing finances.

This could represent unprecedented opportunities for improving hypertension care, especially among vulnerable populations in low- to middle-income countries. However, given the largely unregulated nature of smartphone- and Internet-based technologies, significant concerns have been raised regarding the validity of information and BP measurement technologies easily available to patients with hypertension [12••, 13]. As a result of these concerns, adoption of these m-health technologies has generally been slow among patients and health care providers [14].

In this review article, we discuss how m-health technology can advance hypertension management. First, we address how m-health systems can improve medication adherence and patient-physician communication. Second, we summarize how m-health systems can provide patient-directed feedback. Third, we examine how m-health systems can benefit health care providers. Fourth, we review outcomes of smartphone applications on BP control. Fifth, we explore new technologies for measuring BP, including the use of m-health systems as point-of-care BP sensors.

Mobile-Health as a Tool for Managing Hypertension

Smartphone-based m-health systems have a myriad of unique features ranging from providing high-quality patient feedback to enhancing patient-physician communication. These features can improve management of chronic health conditions such as hypertension (Fig. 1). Several studies have shown that ambulatory BP measurements are more strongly associated with the risk of all-cause and cardiovascular mortality than the usual BP measurements in clinics [15, 16]. To this effect, m-health applications can facilitate ambulatory BP monitoring by providing reminders and alarms for patients to check their BP at prescheduled times, and subsequently providing a platform to record BP data within the application [17]. With a reliable store of ambulatory BP data, physicians may feel more confident adjusting BP medications during clinic visits. Often times, m-health systems connect to the patient's electronic medical record so physicians can monitor patients' BP trends remotely and make medications adjustments without requiring an office visit [18]. Additionally, some systems have the potential to go a step further and function as point-of-care BP monitors. While this can appear very alluring, many of these m-health applications with point-of-care BP sensors must still undergo rigorous testing and validation before they can replace automated sphygmomanometers [19]. Finally, m-health systems can also provide patient-directed feedback in the form of illustrating patients' BP trends [20]. Patients can view how strict medication compliance and lifestyle modification improve BP control. This feedback system can provide positive reinforcement for "good" behaviors and negative reinforcement for "bad" behaviors.

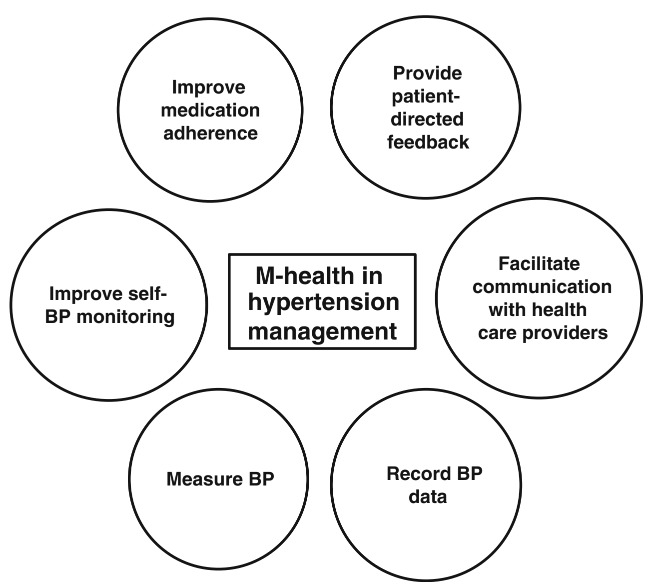

Fig. 1 Various functions of m-health in hypertension management

Recording Patient Data and Enabling Communication With Health Care Providers With Mobile-Health Applications

Most m-health applications obtain BP data using wireless or Bluetooth-enabled technology and then transmit the data to a secure server where both the patient and the health care providers can access the information [18, 21–23]. Because both parties review the data, mobile-health applications can improve patient-physician communication [21, 24]. In a prospective observational cohort study of 484 patients, patients with uncontrolled hypertension were given BP monitors that transmitted patients' BP logs via Bluetooth or a USB cable to an iPhone, iPad, iPod Touch, or Android device. This system not only allowed patients to review their BP readings but also allowed the patients' team of nurses and clinicians to review the BP database and subsequently address critical BP values. The study showed that BP control rates improved from 42% to 67% in patients using the m-health system compared with matched control patients who improved from 59% to 67% ($p < 0.01$) [22]. A cluster-randomized control trial evaluated the efficacy of an automated, web-based, self-management program at in improving blood pressure control among 404 employees of a large corporation. They received home BP cuffs that transmitted readings to a website where they would review BP trends and received automated feedback. The intervention group participants using the m-health system experienced a significant improvement in diastolic BP and reported improved communication with their physicians [21]. Because m-health applications can store data on secure servers where patients and health care providers can review this data, these applications have the potential of improving patient-physician communication. While the mutual review of BP data can strengthen patient-physician communication, providers must take note of privacy concerns relating to m-health. Patient collected health care data, such as BP readings, can be compromised prior to storage on the secure servers since most patients will use personal or perhaps even public wireless networks to transmit this information. Such privacy concerns further highlight the importance of developing validated m-health applications.

Medication Adherence With Mobile-Health Applications

Mobile-health applications that remind patients to take their medications have been shown to improve medication adherence and BP outcomes in hypertensive patients [25]. In one study, 50 high-risk urban patients were provided with a smartphone application that reminded them to take their medications. The study found an improvement in BP with the smartphone application, given patients' baseline BP averaged 144/80 and subsequently decreased to 136/84 after 3 months of using the smartphone application ($p = 0.004$) [26]. In the INTERACT trial, 303 patients taking anti-hypertensive and lipid-lowering medications were subject to a text-message reminder system to determine if reminders can improve medication compliance. The study found that patients receiving text messages were more compliant with their medications, as noncompliance rates in the text message group were only 9% whereas noncompliance rates in the control group were 25% ($p < 0.001$) [27]. Another study with 24 post-stroke hypertensive patients demonstrated improvement in systolic BP in patients who received daily text message reminders to measure BP and take medications [28]. A similar text-messaging m-health system was implemented in a group of 20 hypertensive kidney transplant patients with a history of medication noncompliance. This study also found that text messages reminding patients to take their medications improved medication adherence and BP outcomes [29].

Mobile-Health as a Feedback Tool for Patients

By providing real-time feedback about BP trends, physical activity levels, and dietary sodium intake, smartphone- and website-based m-health applications can show patients how medication adherence and lifestyle modifications improve the management of hypertension. Routine feedback can increase patient autonomy by making patients more aware of their disease process and better understand how factors such as medications, exercise, and dietary habits affect hypertension. Increasing patient autonomy has been shown to improve clinical outcomes when compared to more traditional models of information-only patient education [30]. Studies have demonstrated that m-health systems providing feedback can improve BP outcomes [31, 32]. However, the method of delivering this feedback matters. Most studies suggest that patients alone cannot meaningfully interpret BP trends and require assistance from a pharmacist, nurse, or mid-level provider to interpret or explain BP data.

Three m-health studies—in which patients were expected to interpret website or smartphone feedback alone, without assistance from health care providers—failed to demonstrate improvement in BP outcomes. In a sub-study of a randomized control trial evaluating 95 hypertensive patients, patients used a wireless self-monitoring system linked to a website where they could learn about hypertension, receive reminders about a healthy lifestyle, and access a portal with their BP trends.

The authors found that while wireless self-monitoring m-health systems increased patients' confidence and knowledge about hypertension management, they did not lead to a reduction in systolic BP [23]. A randomized control trial with 500 patients studied the effects of a questionnaire-based m-health system on BP control over a 12-month period. Based on the results of the questionnaire, the m-health site would generate patient-specific questions that each patient could ask his or her PCP to learn more about their hypertension management. The study found no significant difference in BP control between the intervention and control group where mean BP were 128/74 and 129/74, respectively ($p = 0.88$) [33]. Another cluster-randomized control trial with 600 patients examined if an automated, web-based, patient feedback system improved BP control among patients. The study found a modest, but statistically significant decrease in diastolic BP of 2.6 mmHg ($p < 0.001$), but no difference in systolic BP after the intervention [21].

Utilizing health care providers, such as nurses, pharmacists, or physicians, to explain or interpret m-health feedback can increase patient engagement with the m-health system, thereby improving BP outcomes [20, 31, 32]. Green et al. performed a randomized control trial with 778 patients and illustrated that home BP monitoring and a web-based interface aiding with hypertension self-management (i.e., viewing medical record, ability to refill medication, access to an online health library with resource on lifestyle modifications) did not improve BP. However, when this m-health system was supplemented with a clinical pharmacist who communicated with patients every 2 weeks, this led to a significant decrease in systolic BP by 14.2 mmHg vs a decrease of only 8.2 mmHg in the patient-only group ($p < 0.001$) [34]. Similarly, Margolis et al. conducted a randomized control trial with 450 patients and found that the combination of home BP telemonitoring and frequent reminders from pharmacy case managers about medication adherence and lifestyle modifications resulted in 71.8% of patients achieving goal BP at 6 months, whereas only 45.2% of control group achieved goal BP ($p < 0.001$). Even after 18 months, 71.8% of the telemonitoring group continued to remain at goal BP while only 57.1% of the control achieved goal BP ($p = 0.003$) [35]. Piette et al. conducted a randomized control trial of 72 patients and examined if m-health technology and BP telemonitoring can improve BP outcomes. This study did not use pharmacist feedback but instead used automated weekly phone calls reminding patients to measure daily BP, take their antihypertensive medications, and make healthy lifestyle choices. This m-health system did not improve BP outcomes [32].

These studies suggest that supplementing website and smartphone application feedback with additional feedback from mid-level providers improves BP outcomes. There may be several reasons for this finding. Perhaps the pharmacists and mid-level providers relay BP trends to physicians directly and urgently, resulting in more frequent uptitration of BP medications compared to systems where patients review their own BP data and must wait until the next appointment for uptitration of medications. Additionally, health literacy may play a role in whether or not patients can autonomously interpret website or smartphone feedback to meaningfully impact hypertension management. One study's subgroup analysis showed that patients with higher health literacy more successfully interpreted m-health feedback than patients with lower health literacy; however, this was not the study's primary outcome [23]. Green et al. and Margolis et al. did not stratify patients based on their health literacy, and to our knowledge, there are no studies evaluating the relationship between hypertension m-health feedback on patients of varying health literacy as a primary outcome. Ultimately, the personalized and patient-specific nature of pharmacist and mid-level provider feedback cannot be overlooked, as it may play an important role in achieving better BP control.

While incorporating pharmacist, midlevel provider, or physician feedback into m-health systems may improve BP outcomes, requiring in-person feedback for a mobile-health system to function proves challenging in resource limited settings. The few studies demonstrating that patients alone can interpret m-health feedback in a meaningful way all utilize a text-messaging-based feedback system. In one study, 67 postmenopausal women regularly measured their BP, along with other parameters such as waist circumference, body weight, and diet/exercise habits, and then entered this data into a website accessible by smartphone or personal computer. Instead of receiving feedback from a pharmacist or mid-level provider, these patients received tailored, patient-specific text messages addressing problem areas for each patient. The study found that patients receiving these text messages exhibited a 6.5-mmHg decrease in systolic BP, whereas the control group's systolic BP increased by 0.9 mmHg ($p < 0.001$) [24]. Another randomized control trial with 121 patients established that both unidirectional text messaging, where patients received a reminder to check BP, and bidirectional text messaging, where patients were asked to provide a BP measurement in response to the reminder text message, resulted in patients more consistently tracking their outpatient BP [36]. Another randomized control trial subjected 244 diabetic patients who also had uncontrolled hypertension to a home BP telemonitoring system that delivered patient-directed self-care messages to a smartphone immediately after the patient measured their BP. They found that patients receiving these text messages had a systolic BP 7.1 mmHg lower than those not receiving the text messages at the end of the study ($p < 0.005$) [37]. The StAR trial, which evaluated the role of interactive text messages on BP outcomes in a primary care setting in South Africa, did not show an improvement in BP with interactive text messaging [38, 39]. This study, however, enrolled mostly patients with well-controlled hypertension, and this may explain why a profound change in BP after implantation of text messages was not observed.

Mobile-Health as a Tool for Health Care Personnel

In addition to helping providers review patients' BP data remotely and make medication adjustments, m-health applications can also benefit health care personnel in the patient intake and triage process, especially in high-volume clinical settings. The mPower Heart Project examined the effects of mDSS, a nurse-utilized smartphone application that screened for hypertension and diabetes, among patients establishing care at a particular clinic. When a nurse facilitated the intake of a patient, he or she would obtain the patient's demographic data, medical history, BP, and fasting blood glucose, enter this data into the mDSS, and then the mDSS would generate a management plan for the patient. An attending physician would review the mDSS plan and either approve or reject the plan. The study found that over an 18-month period, the mDSS resulted in a 14.6 mmHg (95% CI − 15.3 to − 13.8) and 7.6 mmHg (95% CI − 8.0 to − 7.2) decrease in systolic and diastolic BP, respectively, compared to baseline BP data [40]. The SimCard trial conducted in rural China and India revealed similar findings. In this study, community health workers who worked under the supervision of physicians utilized a smartphone application that functioned as an electronic medical record. The software also recommended escalation of therapy based on a patient's BP; physicians would review these recommendations and approve them when appropriate. The study found the smartphone application led to a 25.5% increase ($p < 0.001$) in antihypertensive use compared to the control group, whose health care was not managed by the smartphone application [41].

Both of these studies illustrate that in communities with large clinical volume, shortage of primary care physicians, or a paucity of resources in general, applications like the mDSS can easily screen for chronic illnesses such as hypertension. Promising findings such as these has prompted Jha et al. to undertake a randomized control trial studying whether or not a mobile application named mWellcare can achieve better BP outcomes [42]. Similar to the mDSS, mWellcare will be utilized by clinic nurses who facilitate patient intake, and the Android-based application will screen for hypertension and diabetes, as well as provide information about lifestyle modifications.

Blood Pressure Outcomes Using Smartphone Applications

Several studies have demonstrated how smartphone applications can improve hypertension management [20, 43–45] While there are no studies showing that use of commercially available smartphone applications improves BP outcomes, there are studies in which researchers engineered their own smartphone application to demonstrate that smartphone applications can improve hypertension management if coupled with feedback from health care providers (Table 1) [18, 45, 46]. The POST pilot study compared BP outcomes between patients using a home BP monitoring system and a smartphone application to a control group without the smartphone application. Their smartphone application not only transmitted patients' BP to a central platform for physicians to review but also set alarm reminders for patients to take their medications and functioned as an educational tool with a Q&A section on hypertension. They found that 72.3% of hypertensive patients using the smartphone application achieved BP < 140/90 mmHg by the end of the study, whereas only

Table 1 Summary of BP outcomes in three studies evaluating smartphone application based m-health systems

Study	Design	Population	Study intervention	Results
Albini et al. (2016) [45]	Pilot study, 6 months	690 patients with uncontrolled hypertension	Use of a m-health system with (1) wireless BP monitoring, (2) smartphone application, and (3) web-based server for patients and physicians to review BP data	A higher rate of office BP control of 72.3% in mobile-health group vs 39.9% office BP control in standard of care patients ($p < 0.0001$)
Earle (2010) [18]	Pilot study, 6 months	137 patients with diabetes and hypertension	Use of a mobile telemonitoring application with (1) wireless BP monitoring, (2) smartphone application, and (3) web-based application for physicians to review BP data	Decrease in systolic BP by 6.5 mmHg in the mobile-health group vs 2.1 mmHg in the control group ($p = 0.027$)
Morawski et al. (2018) [47••]	RCT, 12 weeks	411 patients with uncontrolled hypertension	Use of a m-health system with (1) reminders/alarms for patients to take their medications, (2) weekly medication adherence reports, (3) BP trending for patients, and (4) ability to assign a "Medifriend" who can keep patient accountable with medication compliance	No significant difference between m-health group and control which demonstrated 10.6- and 10.1-mmHg decrease in systolic BP ($p = 0.78$) after 12 weeks, respectively

39.9% of the hypertensive control group patients achieved BP < 140/90 ($p < 0.0001$) [45]. A pilot study by Earle et al., which used a combination of wireless BP monitoring and smartphones, also demonstrated improvement in BP. The study showed a 6.5-mmHg decrease (95% CI − 0.8 to − 12.2) in systolic BP in the smartphone application group, while only a 2.1-mmHg decrease (95% CI 9.3 to − 5.0) in systolic the BP in the control group [18]. The 411 participant MedISAFE-BP randomized control trial, which studied the medisafe smartphone application, failed to demonstrate a statistical difference in systolic BP between medisafe users and the control group. This m-health application emphasized medication adherence as a means to improve BP control. Medisafe users received daily reminders and alarms to take their medications, weekly medication adherence reports, and could also appoint a "medifriend" who reviews the users' medication history in efforts to foster accountability [47••].

In Earle et al. and the POST study, both which showed positive BP outcomes with m-health systems, BP measurements were wirelessly transmitted to the smartphone, where patients monitored their BP trends, and to a central website or server, where physicians reviewed BP data. Notably, the application from the POST trial also offered more feedback for patients, as it reminded them to take their medications and functioned as an educational tool with a Q&A section on hypertension. On the other hand, the medisafe application did not wirelessly transmit BP data to a central server for health care providers to review and provide feedback to patients. As discussed before, perhaps the absence of oversight and feedback from health care providers is why the medisafe application did not show improvement in BP outcomes. Moreover, the MedISAFE-BP trial had a shorter study duration of 12 weeks, whereas Earle et al. and the POST study both had a study duration of 6 months. Perhaps the outcome of the MedISAFE-BP trial would have been different with a longer study duration.

Results from more randomized control studies comparing m-health applications to the standard of care are needed to determine whether or not use of smartphone applications improves BP outcomes. However, positive findings from the POST study have led to the marketization of this smartphone application, and it is now available for download on Google Play and iTunes under the name ESH CARE [48].

Using M-Health Smartphone Applications for Point-of-Care Blood Pressure Measurements

M-health smartphone systems obtain BP data in three ways: manual entry of BP recordings by patients, wireless or Bluetooth-enabled oscillometric BP cuffs that transmit data to the smartphone, and smartphones obtaining BP data via cuffless BP technology [19, 22, 24, 35, 37]. Each modality has its advantages and disadvantages, as summarized in Table 2. Several studies have validated the use of oscillometric BP devices, illustrating no significant difference between oscillometry and mercury sphygmomantometry, the gold standard for BP measurement [49, 50]. Both physicians and patients widely utilize oscillometric BP devices due to their ease of use, convenience, and ability to wirelessly transmit BP measurements to m-health devices such as smartphones or websites. However, the biggest challenge with oscillometric BP devices is finding the appropriate cuff size for each patient, given a poorly fitting cuff leads to inaccurate BP measurements [51]. Moreover, the need for a cuff and machine limits patients to measuring their BP at home or clinic setting, making it difficult for patients who travel frequently or patients with busy jobs and schedules to monitor their BP regularly [17].

Table 2 Advantages and disadvantages of mercury sphygmomanometry, oscillometric BP monitoring, and cuffless BP monitoring

Method of measuring BP	Advantages	Disadvantages
Mercury	• Gold standard	• Technique requires proficiency in auscultation • Inability for patient to measure their own BP • Incorrect cuff size leads to inaccurate BP measurements
Oscillometric BP monitor	• No technical skills such as auscultation required • Ability to transmit BP data from the oscillometric machines to a remote server via wireless or Bluetooth technology	• Overestimation of BP in patients with less compliant vessels like the elderly • Incorrect cuff size leads to inaccurate BP measurements
Cuffless technology	• Ease of use and possibility of smartphone measuring BP directly • Eliminates need for a cuff, given incorrect cuff size is a huge driver of inaccurate BP measurements	• Absence of large clinical trials validating cuffless technology • Many studies are "proof of concept" only • Clinicians more weary of cuffless data due to lack of familiarity, and may be less likely to make medication changes based on cuffless BP data

The limitations seen with cuff-based methods have spawned a growing interest in photoplethysmogram (PPG) sensor-based cuffless BP technology. PPG sensors extrapolate a patient's BP by obtaining information about the cardiac cycle via optic measurements. Some newer-generation smartphones have cameras that can function as PPG sensors. Patients merely press their finger against the sensor and they receive a BP measurement [52•, 53•]. Such technology may not only circumvent the issue of poorly fitting cuffs with oscillometric and mercury machines but also offer potential for patients to measure their BP anytime and anywhere without extra machinery such as the cuff, machine, and stethoscope [17]. This may increase patients' adherence to routine home BP monitoring. Unfortunately, many of these cuffless technologies have not been systematically reviewed or validated. Very little research has been performed comparing the accuracy of BP recordings obtained from smartphone-based cuffless technology to those recording obtained via mercury sphygmomantometry or oscillometric machines.

Per our literature review, few studies have compared smartphone-based cuffless BP measurements to the standard of care, oscillometry, or mercury sphygmomantometry. These studies suggest that cuffless technology may have a promising future, but underscore that the few commercially available smartphone applications, which have been tested, have overwhelmingly failed validation trials. In one study with 35 subjects, smartphones with PPG sensors measured patients' BP when the patients pressed their finger on the smartphone screen with varying degrees of force. The finger pressing emulates a BP cuff in that both externally compress an artery to generate variable-amplitude oscillations. The study found similar bias and precision error between cuffless smartphone BP and finger cuff-based oscillometric BP recordings, which functioned as the control [54•]. Another study with 172 subjects examined the validity and reproducibility of a cuffless sensor utilizing PPG technology to measure BP. The study found good reproducibility between BP measurements obtained from PPG sensors compared to measurements obtained from cuff-based sphygmomanometry with an intraclass correlation coefficient (ICC) of 0.918 and 0.842 for systolic and diastolic BP measurements, respectively [55•]. A subgroup analysis of the iPARR trial attempted to validate a PPG sensor-based smartphone algorithm for measuring BP using the European Society of Hypertension (ESH) International Protocol. Thirty-two pregnant women used the PPG smartphone algorithm to measure their BP, and the recordings obtained by the smartphone did not meet ESH validation criteria, as the smartphone algorithm overestimated lower reference range BP and underestimated higher reference range BP [53•]. In an 85 participant study, Plante et al. measured the accuracy of the "Instant Blood Pressure app." (IBP), a commercially available smartphone application where users obtain BP recordings by placing their right index finger over the smartphone's camera. The study found that the IBP app has a lower sensitivity for high BP measurements and that up to 77.5% of users with hypertensive BP may be inappropriately deemed normotensive [52•].

The fact that the IBP application has been downloaded more than 148,000 times illustrates patients' growing interest in m-health applications. While smartphone-based cuffless technology offers great promise for obtaining rapid, on-the-go BP measurements, the absence of validated smartphone applications makes it dangerous for patients and providers alike to make clinical decisions based on these BP recordings. Moreover, the few studies attempting to compare smartphone-based cuffless measurement to oscillometry or mercury sphygmomantometry are limited by small sample sizes. A recent cross-sectional study reviewing 107 commercially available smartphone applications pertaining to hypertension found that less than 3% of smartphone applications were engineered using the input or guidance of a health care agency [12••]. Perhaps if more of these applications were engineered by health care personnel and scientifically validated, patients and providers could more reliably use smartphone point-of-care BP data to titrate antihypertensives in the outpatient setting.

Conclusions

The use of validated m-health applications can improve BP outcomes through the multimodal approach of reminding patients to take their medications, providing patient-specific feedback about BP trends, and improving patient-physician communication. While m-health applications can increase patient autonomy and involvement in chronic disease management, the applications still rely on oversight from health care providers. Applications that incorporate this oversight and feedback appear to more significantly improve BP than applications that lack this physician or health care provider oversight. While studies show that in concept point-of-care BP measurements can be obtained via PPG technology, most of the applications using PPG sensors have not been scientifically validated and often report erroneous BP measurements. Patients and providers alike must cautiously interpret these point-of-care measurements and corroborate these measurements against oscillometry or mercury sphygmomanometery data. Smartphone applications that provide patients with medication reminders, that give patients directed feedback, and that communicate with patients' health care providers can function as an effective tool for improving BP outcomes.

Compliance with Ethical Standards

Conflict of Interest Neela D. Thangada, Neetika Garg, Ambarish Pandey, and Nilay Kumar declare that they have no conflict of interest.

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

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