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Efficacy of Smartphone Applications in Hypertension Management: A Systematic Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Background: Hypertension is a global health challenge, affecting over a billion individuals worldwide. Despite the availability of effective treatments, control rates remain suboptimal. Emerging technologies, such as smartphone applications, offer new avenues to enhance hypertension management. This systematic review aims to evaluate the effectiveness of smartphone applications in hypertension management.

Methods: To provide a comprehensive overview of the current evidence, we systematically searched PubMed, EMBASE, and the Cochrane Library for both randomized controlled trials (RCTs) and non-randomized clinical trials that examined the use of smartphone applications in hypertension management. Our search included all relevant studies published until June 2023. Studies were selected based on predefined criteria relating to study design, patient population, intervention type, and outcome measures. Data were extracted and analyzed by two independent reviewers. The primary outcome of interest was blood pressure control, while secondary outcomes included medication adherence and health-related knowledge.

Results: From our systematic search, a total of 11 RCTs involving 1,685 participants met our inclusion criteria and were included in the review. The smartphone-based interventions varied widely across studies, ranging from simple text reminders to comprehensive digital therapeutics systems, and including education-based applications, self-monitoring programs, and telemonitoring systems. Collectively, these interventions demonstrated significant improvements in blood pressure control in the intervention groups compared to the standard care. Additionally, they showed increased medication adherence and enhanced health-related knowledge, suggesting potential benefits beyond blood pressure control.

Conclusion: The reviewed studies suggest that smartphone applications may provide a beneficial tool for managing hypertension. They show improvements in blood pressure control, medication adherence, and health-related knowledge. These findings underline the potential of digital health interventions to address a global health concern. Nevertheless, further robust, well-designed RCTs are needed to corroborate these findings and explore the long-term effectiveness, sustainability, and cost-effectiveness of smartphone applications in hypertension management. With the rapid advancement in technology, the role of digital health in hypertension management is likely to become even more critical and complex, making this an area of crucial importance for future research.

Keywords: Hypertension; smartphone applications; blood pressure control; medication adherence; mHealth; randomized controlled trials.

1. INTRODUCTION

"Hypertension, also known as high blood pressure, is a prevalent chronic disease that has significant implications for public health worldwide. It is a condition where the pressure in the blood vessels is persistently elevated, often defined as a systolic blood pressure of 140 mmHg or higher, or a diastolic blood pressure of 90 mmHg or higher" [1]. "According to the World Health Organization (WHO), hypertension affects over 1.13 billion individuals globally, contributing to the burden of heart disease, stroke, and kidney failure, and ultimately premature mortality" [2]. "Despite the availability of effective treatments, control rates of hypertension are suboptimal globally, with less than 20% of people with hypertension achieving optimal blood pressure control" [3].

Hypertension management is multifaceted and extends beyond merely prescribing medication. It involves regular monitoring of blood pressure, adherence to prescribed medication, dietary modifications, regular physical activity, and reduction of alcohol and tobacco use [4,5,6]. However, traditional models of healthcare delivery often struggle to support these elements of hypertension management effectively. Barriers such as accessibility, cost, and patient adherence contribute to the underachievement in controlling this pervasive condition [7].

In recent years, advancements in technology have paved the way for new approaches to health care delivery and management. One such promising area is mobile health (mHealth), defined by the Global Observatory for eHealth as "medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices" [8]. Specifically, the use of smartphone applications in chronic disease management, such as hypertension, is burgeoning.

Smartphone applications, or "apps," are software applications designed to run on mobile devices. They are easily accessible, user-friendly, and can deliver various health services ranging from providing health information to monitoring disease parameters, promoting healthy behaviors, and facilitating communication with health care providers [9]. For hypertension, smartphone apps can offer features like reminders for medication intake, educational information about the disease and lifestyle modifications, tracking of blood pressure measurements, and virtual consultation services.

“The proliferation of smartphone usage worldwide, coupled with the versatility and convenience of these apps, makes them a potentially effective tool for hypertension management. An estimated 3.8 billion people, nearly half of the world's population, were reported to own a smartphone in 2021, with numbers continuously rising” [10]. Despite this vast potential, the effectiveness of smartphone applications in hypertension management is still an emerging area of research.

The purpose of this systematic review is to synthesize the current body of evidence regarding the effectiveness of smartphone applications in hypertension management. This research will shed light on how mHealth can be optimized and potentially integrated into standard care, contributing to the broader goal of improving hypertension control rates and reducing the global burden of this disease.

2. METHODS

This systematic review was conducted in adherence to PRISMA Statement 2020 guidelines. The guidelines set forth by the declaration of Helsinki was adhered to during the course of this study to ensure that all ethical guidelines were adhered to.

2.1 Eligibility Criteria

- **Participants:** Studies involving patients diagnosed with hypertension were included. Both newly diagnosed and long-standing hypertensive patients were considered, with no age or gender restrictions.
- **Intervention:** Studies investigating the use of smartphone applications in the management of hypertension were included. Specifics of the applications, such as their features, frequency of use, and duration of intervention, were noted.
- **Study Design:** Both randomized controlled trials (RCTs) and non-randomized clinical trials were included to gather a broad range of evidence.
- **Outcome Measures:** Studies were required to report on changes in systolic and/or diastolic blood pressure, medication adherence, and any other relevant clinical or behavioral outcomes.

2.2 Exclusion Criteria

- Studies were excluded if they did not focus on hypertensive patients or did not use a smartphone application as an intervention.
- Case reports, review articles, and studies with incomplete or insufficient data were also excluded.

2.3 Information Sources

We searched the following databases: PubMed, Embase, Cochrane Library, and Web of Science. Manual searches were also conducted in relevant conference proceedings and in the bibliographies of included studies to identify potential additional eligible studies. The search was limited to studies published in English involving human subjects.

2.4 Search Strategy

The search strategy combined Medical Subject Headings (MeSH) and free-text terms, including "Hypertension", "Smartphone Application", "Mobile Health", "mHealth", "Blood Pressure Control", "Medication Adherence". The search was conducted up until June 2023.

2.5 Study Selection

Titles and abstracts of studies retrieved using the search strategy were screened independently by two reviewers for eligibility. Full-text articles of potentially eligible studies were then retrieved and further assessed against the inclusion and exclusion criteria. Any disagreements were resolved through consensus or, if unresolved, by consulting a third-party arbitrator who is an expert in the field of mobile health applications for chronic disease management.

2.6 Data Extraction and Synthesis

Data extraction was conducted by two independent reviewers. When discrepancies occurred, the reviewers first attempted to resolve these through discussion, elaborating on their rationale and re-evaluating the relevant data together. If disagreements persisted, the protocol stipulated an escalation to a senior reviewer. This senior reviewer, an expert with extensive experience in systematic reviews and mobile health interventions, was tasked with making the final decision to ensure a balanced and fair evaluation of the data extracted. The extracted data included study characteristics (author, year of publication, study design), participant demographics, intervention details, outcome measures, and findings. Given the likely heterogeneity in smartphone application interventions and outcome measures, a narrative synthesis approach was planned. Findings from the included studies were reported descriptively, highlighting the strengths and limitations of each study and emphasizing implications for clinical practice and future research directions.

3. RESULTS

Of the 658 studies identified from databases, 71 duplicates were removed. In the screening phase, 587 studies were screened for titles and abstracts, wherein 526 of them were excluded due to lack of relevance. In the full-text reviewal phase, 61 studies were assessed, of which 11 were included in this systematic review. The PRISMA flowchart is depicted in Fig. 1.

Bhandari et al. conducted “a randomized controlled pilot trial to test the effectiveness of a mobile phone text messaging intervention (TEXT4BP) in improving blood pressure control among hypertensive patients in Nepal [11]. The study population comprised 200 individuals with a mean age of 50.5 years, and 44.5% were women. The intervention involved patients receiving text messages three times per week for three months, while the control group received standard care. The study reported a notable reduction in systolic/diastolic blood pressure for the intervention group at -7.09/-5.86 mmHg ($P \leq 0.003$) compared to -0.77/-1.35 mmHg ($P \geq 0.28$) for the control group. The adjusted difference in systolic blood pressure ($\beta = -6.50$, 95% CI, -12.6; -0.33) and diastolic blood pressure ($\beta = -4.60$, 95% CI, -8.16; -1.04) were significant. Furthermore, 70% of patients in the intervention group achieved target blood pressure versus 48% in the control group ($P = 0.006$)”.

Dwairej et al. carried out “a randomized controlled trial to investigate the impact of an educational application intervention on self-care, hypertension-related knowledge, and blood pressure control among 116 adult hypertensive patients from cardiology clinics [12]. The intervention group used an educational application on a mobile device, while the control group received usual care. The findings showed significant improvements in knowledge, self-care, and blood pressure control in the intervention group ($P < 0.05$)”.

In 2022, Ma et al. conducted “a single-blinded randomized controlled trial with a repeated-measures design to evaluate the effects of a smartphone-enhanced nurse-facilitated self-care intervention for Chinese hypertensive patients” [13]. The study included 210 hypertensive patients from two community health service centers in China. The intervention involved six individual weekly education and consultation sessions provided by a nurse in the first six weeks and a researcher-developed smartphone application for 12 weeks. The control group received usual care. The intervention group exhibited significant reductions in systolic blood pressure (T1: $\beta = -7.29$, T2: $\beta = -11.07$), diastolic blood pressure (T1: $\beta = -4.80$, T2: $\beta = -7.50$), body weight, body mass index, and waist circumference. At the 12th week follow-up, the proportion of participants with blood pressure < 140/90 mmHg in the intervention group (31%) was significantly higher than that in the control group (9%, $P = 0.003$).

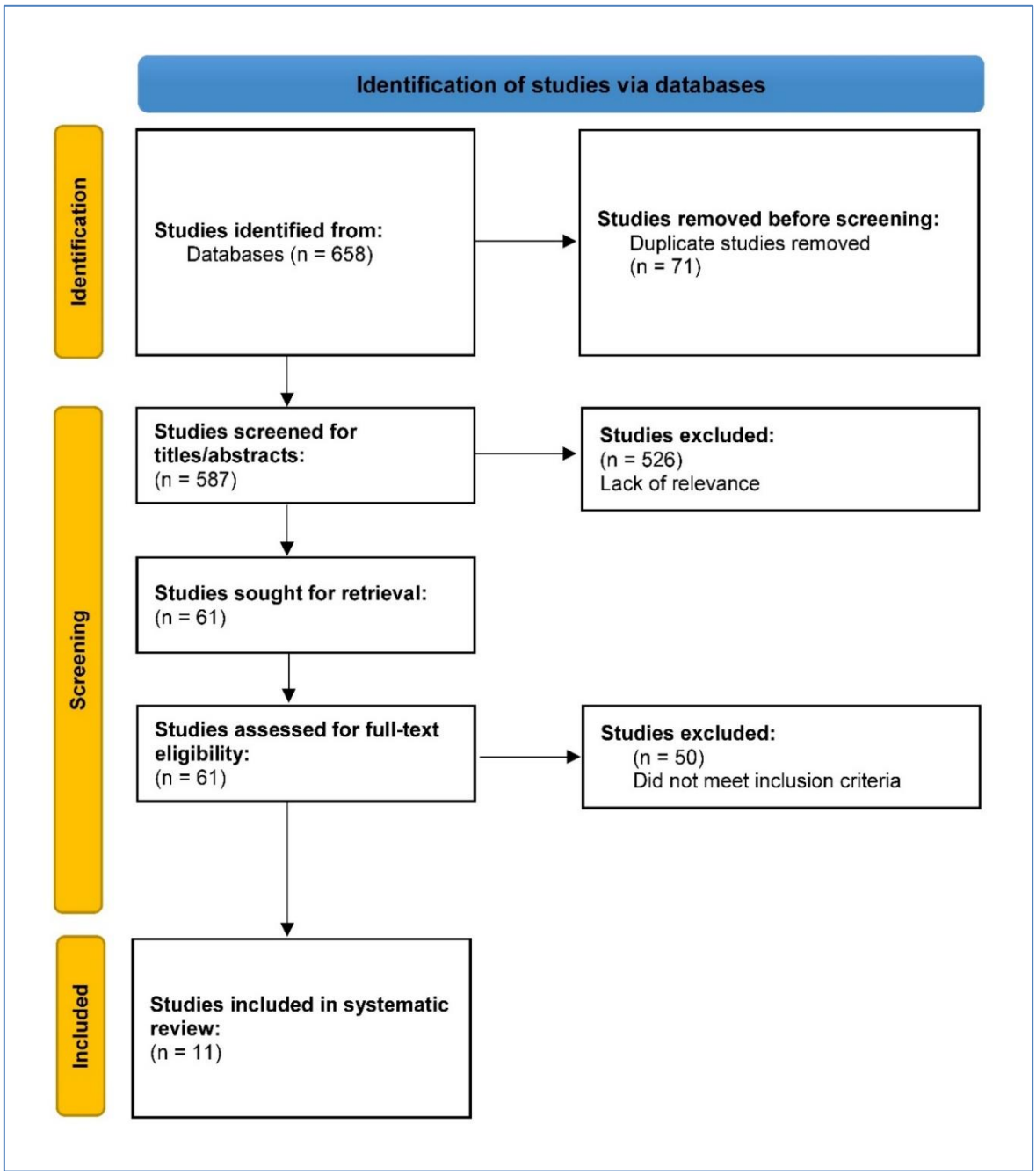

Fig. 1. PRISMA flowchart depicting the study selection process

Kario et al. conducted “a prospective, open-label, randomized controlled study to test the efficacy of a digital therapeutics system in the management of essential hypertension” [14]. The study population consisted of 390 hypertensive patients from Japan who were not receiving antihypertensive medication. The intervention group received the digital therapeutics system combined with standard lifestyle modification, while the control group received standard lifestyle modification alone. The study found significant between-group differences in 24-h ambulatory, home, and office systolic blood pressures (SBPs) at 12 weeks, favoring the intervention group. The differences were -2.4 (95% confidence interval -4.5 to -0.3), -4.3 (-6.7 to -1.9), and -3.6 (-6.2 to -1.0) mmHg, respectively.

Table 1. Characteristics of the included trials

Author, Year	Title	Study Type	Outcome Measures	Population	Intervention	Control	Main Results
Bhandari, [11]	Effectiveness and Acceptability of a Mobile Phone Text Messaging Intervention to Improve Blood Pressure Control (TEXT4BP) among Patients with Hypertension in Nepal: A Feasibility Randomised Controlled Trial	Randomized controlled pilot trial	Change in systolic/diastolic BP and medication adherence at 3 months	200 patients with hypertension from Kathmandu, Nepal (mean age: 50.5 years, 44.5% women)	Patients received text messages three times per week for three months (TEXT4BP)	Patients received standard care	Reduction in systolic/diastolic BP for the intervention group were -7.09/-5.86 mmHg (P ≤ 0.003) vs -0.77/-1.35 mmHg (P ≥ 0.28) for control group. Adjusted difference in systolic BP β = -6.50 (95% CI, -12.6; -0.33) and diastolic BP β = -4.60 (95% CI, -8.16; -1.04). 70% in intervention achieved target BP vs 48% in control (P = 0.006)
Dwairej, [12]	Hypertension and mobile application for self-care, self-efficacy and related knowledge	Randomized controlled trial	Self-care and hypertension-related knowledge, BP control	116 adult hypertensive patients from cardiology clinics	Educational application intervention on a mobile	Usual care	The results showed significant improvement in knowledge, self-care, and BP control in the intervention group (P < 0.05)
Ma, [13]	The effects of a smartphone-enhanced nurse-facilitated self-care intervention for Chinese hypertensive patients: A randomised controlled trial	Single-blinded randomized controlled trial with a repeated-measures design	Blood pressure control, anthropometric parameters (body weight, waist circumference), and self-care	210 hypertensive patients from two community health service centres in China	Six individual weekly education and consultation sessions provided by a nurse in the first 6 weeks and a researcher-developed smartphone application for 12 weeks	Usual care	Significant reductions in systolic BP (T1: β = -7.29, T2: β = -11.07), diastolic BP (T1: β = -4.80, T2: β = -7.50), body weight, body mass index, and waist circumference in the intervention group. At the 12th week follow-up, the proportion of participants with BP < 140/90 mmHg in the intervention group (31%) was significantly higher than that in the control group (9%, P = 0.003).
Kario, [14]	Efficacy of a digital therapeutics system in the management of essential hypertension: the HERB-DH1 pivotal trial	Prospective, open-label, randomized controlled study	Mean change in 24 h ambulatory SBP, office and home BP from baseline to 12 weeks	390 hypertensive patients from Japan not receiving antihypertensive medication	Digital therapeutics system (HERB system + standard lifestyle modification)	Standard lifestyle modification alone	Between-group differences in 24-h ambulatory, home, and office SBPs at 12 weeks were -2.4 (95% confidence interval -4.5 to -0.3), -4.3 (-6.7 to -1.9), and -3.6 (-6.2 to -1.0) mmHg, respectively in favor of the intervention group
Chandler, [15]	Impact of 12-Month Smartphone Breathing Meditation Program upon Systolic Blood Pressure among Non-Medicated Stage 1 Hypertensive Adults	Randomized controlled trial	Change in resting systolic and diastolic BP, adherence to the TT protocol, and perceived stress levels	30 adults (mean age: 45.0 years; 15 males; 16 White; 14 Black) with ACC/AHA 2017 defined systolic HTN (130-139 mmHg)	Participants were trained to perform twice-daily TT for 10 weeks	Participants received a lifestyle education program (LEP) delivered via smartphone for 10 weeks	TT group showed a greater reduction in SBP (TT -15.4 ± 5.3 mmHg vs. LEP -3.2 ± 5.2 mmHg, P = 0.03) at 12 months
Gong, [16]	Mobile health applications	Randomized	Changes in blood	480 participants with	Use of "Yan Fu"	No use of m-health	Intervention group had

Author, Year	Title	Study Type	Outcome Measures	Population	Intervention	Control	Main Results
	for the management of primary hypertension: A multicenter, randomized, controlled trial	controlled trial	pressure, medication adherence, blood pressure control	hypertension	app	app	significantly greater reduction in systolic and diastolic blood pressure, higher medication adherence, and blood pressure control (P < 0.05)
Chandler, [17]	Impact of a Culturally Tailored mHealth Medication Regimen Self-Management Program upon Blood Pressure among Hypertensive Hispanic Adults	Two-arm efficacy trial	Medication adherence, blood pressure control	54 Hispanic adults with uncontrolled HTN	Use of SMASH app with Bluetooth-enabled BP monitor and electronic medication tray	Received text messages with healthy lifestyle tips	Significant reduction in SBP averages at 1, 3, 6, and 9-month time points in SMASH group vs SC group, (P < 0.01). Greater BP control in SMASH group at 3, 6, and 9 months (P ≤ 0.01)
Owolabi, [18]	Randomized Trial of an Intervention to Improve Blood Pressure Control in Stroke Survivors	Randomized controlled trial	Mean change in systolic BP at 12 months	400 stroke patients	THRIVES intervention: patient global risk factor control report card, personalized phone text-messaging, educational video	Control group received text messages, and modest financial incentives	No significant difference in SBP reduction in THRIVES vs control group (2.32 vs 2.01 mm Hg, P=0.82). But for subjects with baseline BP >140/90 mm Hg, significant decrease in mean SBP in both groups
Lakshminarayan, [19]	A mHealth-based care model for improving hypertension control in stroke survivors: Pilot RCT	Randomized controlled trial	Usability, HTN control efficacy	50 stroke survivors	mHealth based care model with smart phone and wireless BP monitor	Usual care	Mean SBP declined significantly in the IA by 9.88 mm, P = 0.005 in ITT and 10.81 mm, P = 0.0036 in AT. Hypertension was controlled in 82% of IA (P = 0.14 in ITT, P = 0.015 in AT)
Kim, [20]	The Influence of Wireless Self-Monitoring Program on the Relationship Between Patient Activation and Health Behaviors, Medication Adherence, and Blood Pressure Levels in Hypertensive Patients: A Substudy of a Randomized Controlled Trial	Randomized controlled trial	Health behaviors, medication adherence, blood pressure control	95 hypertensive patients	Wireless self-monitoring program with mobile app	Standard disease management program	Improvements in patient activation associated with reductions in cigarette smoking (beta =- 0.46, P < 0.001) and blood pressure control (beta = 0.04, P = 0.02). Further reductions in unhealthy behaviors and BP in self-monitoring group

Author, Year	Title	Study Type	Outcome Measures	Population	Intervention	Control	Main Results
Logan, [21]	Effect of home blood pressure telemonitoring with self-care support on uncontrolled systolic hypertension in diabetics	Randomized controlled trial	Systolic BP control, psychological effects	110 diabetic patients with uncontrolled systolic hypertension	Home BP telemonitoring system with self-care messages	Normal care	Mean daytime ambulatory systolic BP decreased by 9.1 ± 15.6 mmHg ($P < 0.0001$) in intervention group, 51% of intervention subjects achieved the BP target compared to 31% in control ($P < 0.05$). However, there was a worsening in depression scale ($P = 0.014$)

Abbreviations: BP: Blood Pressure; TEXT4BP: Effectiveness and Acceptability of a Mobile Phone Text Messaging Intervention to Improve Blood Pressure Control; RCT: Randomized Controlled Trial; CI: Confidence Interval; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; BMI: Body Mass Index; ACC/AHA: American College of Cardiology/American Heart Association; HTN: Hypertension; TT: Twice-daily Tranquil Training; LEP: Lifestyle Education Program; mHealth: Mobile Health; SMASH: Self-Management Automated and Systematic Heuristic; SC: Standard Care; THRIVES: Therapeutic Lifestyle Changes (TLC), Home BP Monitoring, Reminder System, Interactive Voice Response System, Video Education, Self-monitoring; ITT: Intention To Treat; AT: As Treated; IA: Intervention Arm; Source: Author survey report

Chandler et al. carried out “a randomized controlled trial to measure the impact of a 12-month smartphone breathing meditation program on resting systolic and diastolic blood pressure among non-medicated stage 1 hypertensive adults” [15]. The sample was made up of 30 adults with a mean age of 45.0 years; 15 were males, 16 White, and 14 Black. Participants were trained to perform twice-daily transcendental therapy (TT) for 10 weeks while the control group received a lifestyle education program (LEP) delivered via smartphone for 10 weeks. The TT group showed a more significant reduction in systolic blood pressure (SBP) (TT -15.4 ± 5.3 mmHg vs. LEP -3.2 ± 5.2 mmHg, P = 0.03) at 12 months.

Gong et al. conducted “a randomized controlled trial to examine the effects of mobile health applications on the management of primary hypertension” [16]. The study included 480 participants with hypertension. The intervention group used the "Yan Fu" app, and the control group did not use any mobile health app. The study reported a significantly more significant reduction in systolic and diastolic blood pressure, higher medication adherence, and blood pressure control in the intervention group (P < 0.05).

Chandler et al. performed “a two-arm efficacy trial to determine the impact of a culturally tailored mobile health (mHealth) medication regimen self-management program on blood pressure among hypertensive Hispanic adults” [17]. 54 Hispanic adults with uncontrolled hypertension were enrolled in the study. The intervention group used the SMASH app, which was paired with a Bluetooth-enabled blood pressure monitor and an electronic medication tray, while the control group received text messages with healthy lifestyle tips. The study found a significant reduction in systolic blood pressure averages at 1, 3, 6, and 9-month time points in the SMASH group compared to the control group (P < 0.01). Moreover, the SMASH group achieved greater blood pressure control at 3, 6, and 9 months (P ≤ 0.01).

Owolabi et al. conducted “a randomized controlled trial to examine the effectiveness of an intervention aimed at improving blood pressure control in stroke survivors” [18]. The study included 400 stroke patients. The THRIVES intervention consisted of a patient global risk factor control report card, personalized phone text-messaging, and an educational video. In comparison, the control group received text messages and modest financial incentives. The study found no significant difference in systolic blood pressure reduction between the THRIVES and control groups (2.32 vs 2.01 mm Hg, P=0.82). However, for subjects with baseline blood pressure >140/90 mm Hg, there was a significant decrease in mean systolic blood pressure in both groups.

Lakshminarayan et al. carried out “a randomized controlled trial to evaluate the usability and hypertension control efficacy of a mHealth-based care model among 50 stroke survivors” [19]. The intervention group used a mHealth care model with a smartphone and a wireless blood pressure monitor, while the control group received usual care. The study found a significant decline in mean systolic blood pressure in the intervention group by 9.88 mm, P = 0.005 in an intention-to-treat (ITT) analysis and 10.81 mm, P = 0.0036 in an as-treated (AT) analysis. Hypertension was controlled in 82% of intervention group (P = 0.14 in ITT, P = 0.015 in AT).

Kim et al. conducted “a randomized controlled trial to assess the influence of a wireless self-monitoring program on patient activation, health behaviors, medication adherence, and blood pressure levels in hypertensive patients” [20]. The study included 95 hypertensive patients. The intervention group used a wireless self-monitoring program with a mobile app, while the control group followed a standard disease management program. The study found that improvements in patient activation were associated with reductions in cigarette smoking (beta =- 0.46, P < 0.001) and blood pressure control (beta = 0.04, P = 0.02). Furthermore, the self-monitoring group showed further reductions in unhealthy behaviors and blood pressure.

Lastly, Logan et al. carried out “a randomized controlled trial to determine the effect of home blood pressure telemonitoring with self-care support on uncontrolled systolic hypertension in diabetic patients” [21]. The study included 110 diabetic patients with uncontrolled systolic hypertension. The intervention group used a home blood pressure telemonitoring system with self-care messages, while the control group received normal care. The study reported that the mean daytime ambulatory systolic blood pressure decreased by 9.1 ± 15.6 mmHg (P < 0.0001) in the intervention group. Furthermore, 51% of intervention subjects achieved the blood pressure target compared to 31% in the control

group (P < 0.05). However, there was a worsening in the depression scale in the intervention group (P = 0.014).

4. DISCUSSION

In this systematic review, we comprehensively examined the current state of research regarding the efficacy of smartphone applications in hypertension management. The body of evidence presented here highlights the significance of this technology in healthcare and, more specifically, in chronic disease management. Across the globe, hypertension continues to be a primary contributor to cardiovascular diseases, and its effective management is critical in reducing morbidity and mortality rates [22]. The incorporation of smartphone applications in hypertension management protocols appears to be a promising approach. The significance of these applications in healthcare, particularly for chronic disease management, is undeniably large; however, their effectiveness varies significantly across different settings and populations.

Our synthesis revealed that the utility of such applications is underpinned by their facilitation of several key areas of hypertension control: medication adherence, regular blood pressure monitoring, patient education, and lifestyle modifications. Furthermore, the geographic diversity of the studies included in this review underscores the wide-reaching implications of this tool, transcending cultural and regional boundaries. However, it is noteworthy to mention the heterogeneity of the studies in terms of intervention specifics, methodologies, and outcomes measures. Despite these advantages, the review also uncovered substantial heterogeneity in study designs, intervention specifics, and outcome measures, complicating the direct comparison of results and the formulation of generalized conclusions. This diversity, although indicative of the dynamic nature of digital health solutions, poses certain challenges when comparing results or trying to form a conclusive assessment. Yet, it also underlines the adaptability of digital health strategies, which can be customized to meet the requirements of various populations and healthcare settings. The adaptability of digital health strategies is promising, but it necessitates careful implementation to achieve widespread and effective use.

The findings support the role of smartphone applications in enhancing hypertension management. Multiple trials, including those by Bhandari [11], Dwairej [12], Ma [13], and Kario [14], have shown significant reductions in blood pressure measurements in patients using smartphone-based interventions compared to standard care. Additionally, some studies like those by Chandler [15,17] and Gong [16] reported increased medication adherence and blood pressure control among patients who used smartphone apps. These results illustrate the effectiveness of smartphone applications in encouraging positive health behaviors, promoting medication compliance, and enhancing self-monitoring, all crucial elements for effective hypertension management. Despite a few studies such as Owolabi's [18] which showed no significant difference in blood pressure reduction between the intervention and control groups, the overall trend from the reviewed studies leans towards the positive impact of smartphone applications in managing hypertension. Although these results are encouraging, they must be viewed with caution due to the variability in study conditions and methodologies. Although these results are encouraging, they must be viewed with caution due to the variability in study conditions and methodologies.

The rise of smartphone applications in healthcare is undoubtedly related to the broader digital revolution and the push for patient-centered care models [23]. By offering real-time tracking, personalized feedback, and interactive education resources, these applications empower patients to actively participate in their health management. This shift towards active patient engagement can be critical in chronic conditions like hypertension, where sustained lifestyle modifications and medication adherence are crucial for successful management [24]. The need for sustained lifestyle changes and consistent medication adherence in hypertension management makes these tools valuable, yet their real-world applicability must be rigorously tested in longer-term and more diverse population studies.

The current literature suggests an overall positive trend concerning the efficacy of these applications. However, as with any emerging technology, rigorous evaluations and continued research are necessary to optimize their design, assess their long-term impact, and understand their limitations [25]. The diversity in the design and functionality of the smartphone applications across the studies reviewed here highlights the need for standardization and further research on

the most effective features. While the promise of smartphone applications in improving hypertension management is notable, their deployment must be accompanied by efforts to understand and mitigate the barriers to their widespread adoption.

The digital divide should not be overlooked. While these applications have the potential to improve hypertension management, their effectiveness could be limited by accessibility issues, digital literacy, and user acceptance, particularly among older adults [26]. Future research should consider these factors to ensure equitable health benefits. Overall, this review highlights the promising potential of smartphone applications in improving hypertension management. As digital health technologies continue to evolve, it is essential that healthcare professionals and researchers embrace this evolution, navigating through the challenges and learning from the experiences and outcomes shared in the literature [27].

5. CONCLUSION

In conclusion, this systematic review provides substantial evidence that smartphone applications can play an essential role in the management of hypertension. The use of such applications has been associated with significant reductions in blood pressure, increased medication adherence, and improved self-care behaviors among patients with hypertension. While variations exist in the design, implementation, and reported effectiveness of these applications, the potential of mHealth as a tool for chronic disease management is clear. As healthcare continues to evolve, with technology being an ever-more integral part, further exploration and optimization of these digital health interventions are vital. Furthermore, the potential benefits extend beyond individual patient outcomes to broader healthcare systems, where mHealth could be a cost-effective strategy to manage chronic diseases at scale. Therefore, there is a pressing need for stakeholders, including healthcare providers, technologists, policy makers, and patients, to come together to create an enabling environment that leverages the power of mHealth to transform the management of hypertension and other chronic diseases.

6. LIMITATIONS

This systematic review, while comprehensive, does have a few limitations that need to be acknowledged. First, while we have made efforts to include as many relevant studies as possible, some studies may have been inadvertently missed. This is due to the variability in the terminology used to describe smartphone applications in hypertension management across different studies. Secondly, the studies included in this review are highly heterogeneous in terms of the study design, the type and features of the smartphone applications used, the duration of intervention, and the characteristics of the population under study. Thus, a meta-analysis could not be conducted. Lastly, the majority of the studies were conducted in high-income countries, which may limit the generalizability of our findings to lower-income settings where the use of smartphone applications might face additional barriers such as affordability, accessibility, and digital literacy.

7. RECOMMENDATIONS

Given the limitations and the promising findings of this review, several recommendations can be proposed for future research. Firstly, more studies are needed in diverse settings, particularly in low- and middle-income countries, to further validate the effectiveness of smartphone applications in hypertension management and to understand the barriers and facilitators to their use in these contexts. Secondly, further research should focus on determining the specific features of smartphone apps that are most effective in improving blood pressure control. This could guide the design and implementation of future mHealth interventions. Thirdly, more long-term studies are required to assess the sustainability of the effects observed. Lastly, it is recommended that future studies use a standard set of outcome measures to allow for better comparison and synthesis of findings.

8. FUTURE RESEARCH DIRECTIONS

While the current evidence suggests promising outcomes with the use of smartphone applications in managing hypertension, there remain several areas where further research is needed to optimize their effectiveness and integration into healthcare systems. This section outlines key directions for future research based on the findings of this systematic review and the existing gaps in the literature.

1. **Evaluating Long-term Effectiveness and Sustainability:** Future studies should focus on the long-term impact of

smartphone application interventions in hypertension management. Most existing studies provide short to medium-term data; thus, long-term trials are necessary to evaluate sustained blood pressure control, adherence to medication, and lifestyle modifications over extended periods. This will help in understanding whether temporary improvements can be converted into permanent lifestyle changes and long-term health benefits.

2. **Incorporating Advanced Technological Features:** As technology evolves, integrating more sophisticated features into hypertension management apps could enhance their effectiveness. Future research could explore the impact of incorporating artificial intelligence for personalized feedback, machine learning algorithms to predict patient risk or complications, and blockchain technology for secure patient data management.
3. **Comparative Studies on App Features:** There is a need for comparative studies that evaluate the effectiveness of different app features. Understanding which elements—such as medication reminders, dietary tracking, educational content, or interactive components—most significantly impact patient outcomes will guide developers in creating more effective apps tailored to the needs of hypertensive patients.
4. **Impact on Different Demographics:** Exploring the differential impact of smartphone applications across various demographic groups, including age, socio-economic status, and cultural backgrounds, is crucial. This can help customize applications to be more inclusive and effective across a broader spectrum of the population, potentially addressing disparities in hypertension management efficacy.
5. **Integration into Healthcare Systems:** Research should also focus on how these apps can be integrated effectively into existing healthcare frameworks to complement traditional care methods. This includes studying the interoperability of apps with other healthcare IT systems, the role of healthcare providers in supporting app use, and the regulatory implications of mHealth solutions.
6. **Barriers to Adoption and Scalability:** Identifying and addressing barriers to the adoption of hypertension management apps is vital. Studies should investigate factors such as digital literacy, accessibility, cost, and user trust and privacy concerns, which can impede the uptake and scalability of these interventions.
7. **Real-world Effectiveness:** More real-world studies are needed to assess the practical effectiveness of these apps outside the controlled trial settings. Such studies would help in understanding how different variables and the complexities of everyday life influence the outcomes of app-based interventions.
8. **Patient and Provider Perspectives:** Further research should include qualitative studies that explore the perspectives and experiences of both patients and healthcare providers regarding the use of smartphone applications for hypertension management. This will provide insights into user satisfaction, perceived value, and potential resistance or challenges faced by users.
9. **Economic Impact:** Evaluating the economic impact, including cost-effectiveness and return on investment, of integrating smartphone applications into hypertension management protocols would provide valuable data for healthcare policy makers and insurers.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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