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Development and validation of a telemonitoring-based self-management care model for patients with hypertension

Eldawati^{1*}, Abdul Gowi¹, Muhammad Taufik Syastra²

¹Program Studi Keperawatan, Fakultas Ilmu Kesehatan, Universitas Horizon Indonesia

²Fakultas Informatika, Universitas Horizon Indonesia

Corresponding author: *E-mail: eldawatielawati09@gmail.com

Abstract

Background: Hypertension requires continuous self-management to achieve optimal blood pressure control. Telemonitoring can support home blood pressure monitoring and continuous self-management, but previous interventions have varied in their components and healthcare professional support.

Purpose: To develop and validate a telemonitoring-based Self-Management Care Model and evaluate its effectiveness in improving blood pressure among patients with hypertension.

Method: This developmental study included platform design, validation by three experts, performance testing, usability testing involving 30 potential users, evaluation, and refinement. The implementation stage used a two-group pretest-posttest design involving 128 patients with hypertension, comprising 64 intervention and 64 control participants. The intervention group used the platform for two months, while the control group received standard hypertension lifestyle education through brochures. Blood pressure was assessed at T0, T1, and T2. Effectiveness was analyzed using Difference-in-Differences with an intention-to-treat approach.

Results: In the intervention group, systolic blood pressure decreased from 145.60 ± 11.32 mmHg to 140.60 ± 10.11 mmHg, with a mean reduction of 5.01 mmHg ($p < 0.001$), while diastolic blood pressure decreased from 95.21 ± 10.35 mmHg to 86.35 ± 9.32 mmHg, with a mean reduction of 8.45 mmHg ($p < 0.001$). Control-group changes were not significant. DID showed differences in systolic blood pressure at T1 (2.57, 95% CI: 1.32–5.52) and T2 (4.34, 95% CI: 2.44–7.36), and diastolic blood pressure at T1 (2.13, 95% CI: 1.57–4.68) and T2 (3.57, 95% CI: 1.89–6.60).

Conclusion: The model demonstrated potential effectiveness in improving blood pressure control and provides a structured approach to long-term hypertension management.

Keywords: Blood Pressure; Digital Health; Hypertension; Self-Management; Telemonitoring.

INTRODUCTION

Hypertension remains a major global public health challenge due to its high prevalence, chronic nature, and contribution to cardiovascular disease and target-organ damage. The World Health Organization (WHO) estimates that approximately 1.4 billion adults aged 30–79 years worldwide are living with hypertension by 2024, representing nearly one-third of the population in this age group. Approximately two-thirds of adults with hypertension live in low- and

middle-income countries, where the burden of the disease is particularly substantial. The challenge extends beyond its high prevalence to inadequate detection and blood pressure control. Globally, approximately 44% of adults with hypertension are unaware of their condition, while only about 23% have their blood pressure adequately controlled. These findings indicate that effective hypertension management requires more than diagnosis and

pharmacological treatment; it also requires sustainable strategies to promote patient engagement in self-management and long-term disease control (Voelker, 2024; World Health Organization, 2023).

This situation is also relevant in the Indonesian context. According to the 2023 Indonesian Health Survey (SKI), the prevalence of hypertension among adults aged 18 years and older, based on blood pressure measurements, was 30.8%, whereas the prevalence based on a doctor's diagnosis was only 8.6%. This gap of more than 20 percentage points between measured and diagnosed hypertension indicates persistent challenges in the detection of hypertension and awareness of hypertension status in the community. At the provincial level, West Java is among the three provinces with the highest prevalence of hypertension among adults aged 18 years and older, based on blood pressure measurements, at 34.4%. These findings indicate that hypertension in Indonesia is not only characterized by its high prevalence but also by a substantial gap between measured blood pressure levels and individuals' awareness of their hypertension status (Noberta, 2024; World Health Organization, 2023).

Hypertension control is a long-term process that is heavily influenced by patients' ability to practice self-management, including monitoring blood pressure, taking medication as prescribed, adjusting diet, limiting salt intake, engaging in physical activity, maintaining a healthy weight, managing stress, and regularly visiting and communicating with healthcare professionals. The problem is that most of these activities take place outside of healthcare facilities, preventing healthcare professionals from continuously observing patient behavior and changes in their condition. Conventional care models that rely on periodic visits also have limitations in providing rapid feedback when blood pressure changes or when patients experience difficulties in self-management behaviors. Therefore, a care approach is needed that connects patient self-management activities at home with ongoing monitoring and support from healthcare professionals (Burnier & Egan, 2019; Matsumoto et al., 2024; Shen et al., 2020).

Advances in healthcare technology offer an opportunity to address these limitations through telemonitoring systems that integrate home blood pressure self-monitoring with communication and

support from healthcare professionals. Telemonitoring enables routine collection of blood pressure data during patients' daily activities, transmission of these data to healthcare professionals, and their use to provide feedback, education, behavioral reinforcement, and timely follow-up. This approach is consistent with current recommendations for hypertension management, which emphasize access to validated blood pressure measurement devices, ongoing monitoring, and strengthened services at the primary healthcare level (Fletcher et al., 2016; Kario, 2020; Omboni et al., 2020).

Several studies have shown that telemedicine and telemonitoring have the potential to improve hypertension management. The HOME BP randomized controlled trial demonstrated that a digitally supported home blood pressure monitoring intervention resulted in greater reductions in systolic blood pressure compared with standard care. Previous studies reported that home blood pressure telemonitoring combined with web-based consultations improved blood pressure control after one year (Yatabe et al., 2021). Other studies have demonstrated that digital interventions integrating self-monitoring, education, automated messaging, and feedback can improve self-efficacy in hypertension management and that home blood pressure telemonitoring combined with education and remote clinical support can improve blood pressure control and medication adherence. Furthermore, a meta-analysis of six randomized clinical trials involving 1,550 patients showed that pharmacist-supported home blood pressure telemonitoring significantly reduced systolic and diastolic blood pressure compared with standard care. Overall, these findings suggest that integrating telemonitoring with education, feedback, and self-management support has the potential to improve hypertension control. However, variations in intervention components, monitoring intensity, healthcare provider involvement, and patient support strategies across previous studies suggest a lack of an integrated and standardized self-management care model. Therefore, the development and validation of a systematic model tailored to the context of hypertension care are warranted (Matsumoto et al., 2024; McCartney & McManus, 2016; McManus et al., 2021a; Meng et al., 2023).

Eldawati^{1*}, Abdul Gowi¹, Muhammad Taufik Syastra²

¹Program Studi Keperawatan, Fakultas Ilmu Kesehatan, Universitas Horizon Indonesia

²Fakultas Informatika, Universitas Horizon Indonesia

Corresponding author: *E-mail: eldawati09@gmail.com

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However, evidence regarding telemonitoring still reveals several important limitations that are worth noting. Telemonitoring does not automatically result in behavioral change if it serves solely as a means of transmitting blood pressure data. The effectiveness of an intervention is greatly influenced by how monitoring data are translated into feedback, education, goal setting, reinforcement, decision-making, and ongoing support for patients. Furthermore, previous research indicates that not all clinical and behavioral components respond consistently to telemedicine interventions. A recent meta-analysis, for example, found that although blood pressure, self-efficacy, self-management skills, and hypertension literacy improved, several outcomes, such as medication adherence, weight, BMI, and LDL cholesterol, did not show significant differences. This suggests that the use of technology alone is insufficient and that intervention approaches explicitly designed to establish and maintain self-management behaviors are needed (Kassavou et al., 2022; McManus et al., 2021b; Yap et al., 2024; Zhou et al., 2024).

Furthermore, the telemedicine literature on hypertension largely evaluates the effectiveness of intervention components separately, while models that systematically integrate patient self-management processes with telemonitoring mechanisms, healthcare provider responses, and follow-up require further development and testing. A systematic review of telemedicine in hypertension management demonstrated potential benefits for various clinical and behavioral outcomes. However, heterogeneity in intervention characteristics, technology, monitoring intensity, and the form of healthcare professional support made it difficult to determine the most appropriate model structure for consistent application in care (Kassavou et al., 2022; Postel-Vinay et al., 2023).

This gap highlights the need for a self-management care model that goes beyond blood pressure monitoring and integrates measurement, data interpretation, education, self-management

reinforcement, feedback, and healthcare professional follow-up within a structured service flow. Such a model is expected to transform telemonitoring from simply being a blood pressure recording technology into a continuous care mechanism that supports patients in making decisions and maintaining daily hypertension management behaviors. Model development is also crucial to ensure that intervention components have a clear conceptual basis, are relevant to patient needs, are acceptable to healthcare professionals, and have adequate content and structural validity before wider implementation.

Based on this description, there is a need to develop a telemonitoring-based self-management care model that integrates home blood pressure monitoring with education, feedback, self-management reinforcement, and healthcare professional follow-up. Model development requires a validation process to ensure that the constructs, components, relationships between components, and implementation procedures are scientifically grounded and applicable to the context of hypertension patient care. Therefore, this study aims to develop and validate a telemonitoring-based self-management care model for hypertension patients as an integrated approach to support sustainable, patient-centered hypertension management.

RESEARCH METHOD

This study employed a developmental research design followed by an implementation evaluation using a quasi-experimental design. The study consisted of two stages: the development and validation of a telemonitoring-based Self-Management Care Model, and the implementation and evaluation of the model's effectiveness in patients with hypertension. The development phase included platform design, expert validation, usability testing (pilot study), evaluation, and platform refinement. The platform was developed to integrate home blood pressure monitoring with self-management support, including blood pressure monitoring, physical activity, dietary monitoring, and health education.

Eldawati^{1*}, Abdul Gowi¹, Muhammad Taufik Syastra²

¹Program Studi Keperawatan, Fakultas Ilmu Kesehatan, Universitas Horizon Indonesia

²Fakultas Informatika, Universitas Horizon Indonesia

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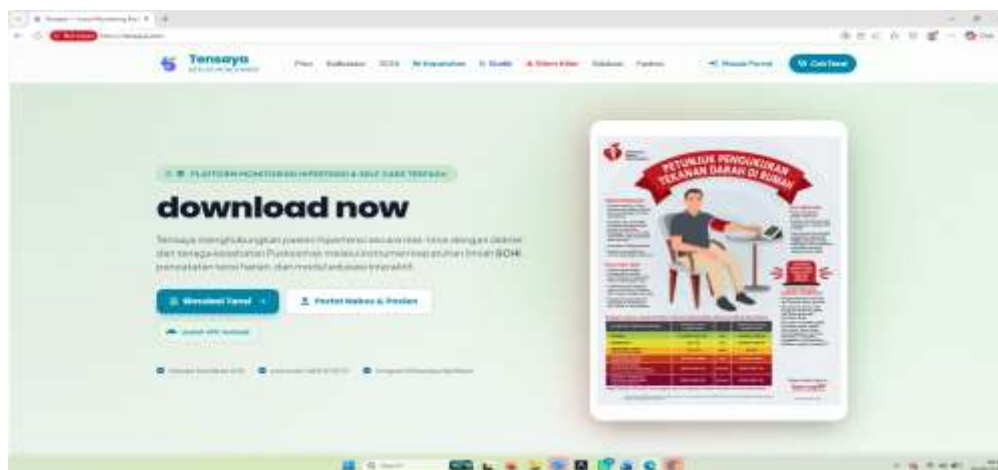


Figure 1. Main interface of the Telemonitoring-Based Self-Management Care platform. (A) Main dashboard

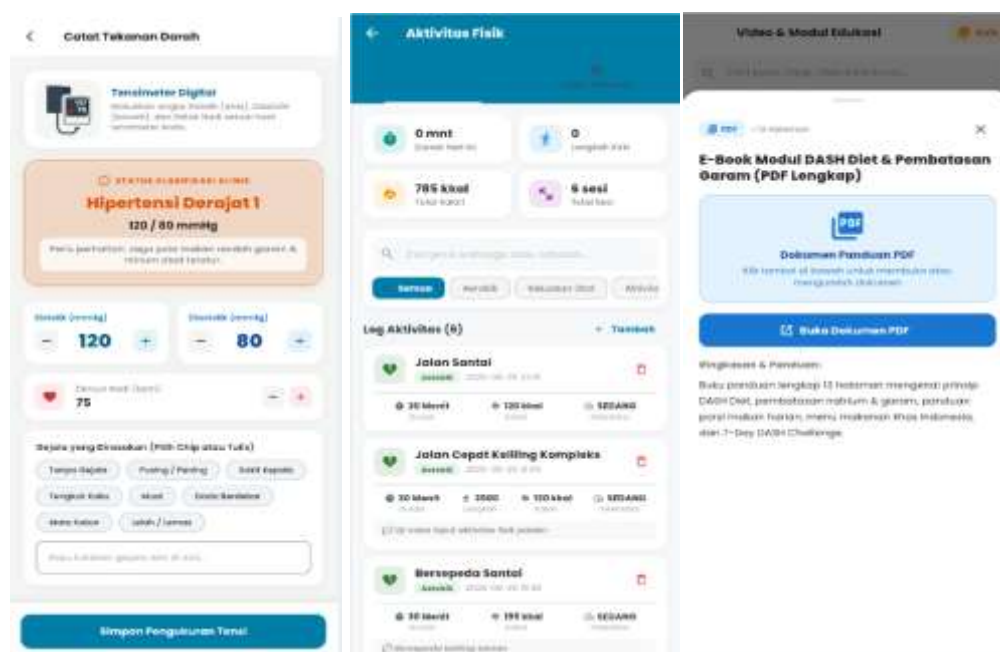


Figure 2. Main features of the Telemonitoring-Based Self-Management Care platform. (B) Blood pressure monitoring; (C) Physical activity monitoring; (D) Dietary monitoring

Validation was conducted by three experts from the fields of nursing, health information technology, and research methodology to assess the suitability of the content, functionality, display, and ease of use. Performance testing was conducted on seven key platform functions, while usability testing was conducted on 30 potential users. The validation results and user feedback were used to refine the platform before implementation. The implementation

phase employed a quasi-experimental design with a two-group pretest-posttest approach. The study was conducted on hypertensive patients at Karawang General Hospital, West Java, Indonesia, with 128 participants: 64 in the intervention group and 64 in the control group. The intervention group used a telemonitoring-based mobile Self-Management Care platform for two months, while the control group received standard education on hypertension lifestyle

Eldawati^{1*}, Abdul Gowi¹, Muhammad Taufik Syastra²

¹Program Studi Keperawatan, Fakultas Ilmu Kesehatan, Universitas Horizon Indonesia

²Fakultas Informatika, Universitas Horizon Indonesia

Corresponding author: *E-mail: eldawatiel dawati09@gmail.com

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modifications through brochures. Blood pressure measurements were taken at T0 (baseline), T1 (first month), and T2 (second month).

Prior to the intervention, participants in the intervention group were provided with a blood pressure monitor and received training on the device and platform in two 45–60-minute sessions. The platform was used for blood pressure recording, symptom monitoring, measurement reminders, medication information, and self-management support. Participants measured their blood pressure at home as scheduled and entered the results into the platform. Researchers also conducted telephone follow-up to monitor platform use and provide support throughout the intervention. The primary outcomes of the study were systolic and diastolic blood pressure. Participant characteristics were analyzed descriptively using means and standard deviations for numerical data and frequencies and percentages for

categorical data. The effectiveness of the intervention was analyzed using Difference-in-Differences (DID) with an intention-to-treat (ITT) approach to compare changes in blood pressure between the intervention and control groups from T0–T1 and T0–T2. Results are presented as DID coefficients with 95% confidence intervals (CI), with a statistical significance level set at $p < 0.05$.

The study has obtained ethical approval from the Health Research Ethics Committee of the PPNI Nursing School, West Java, Indonesia, under permit number III/088/KEPK-SLE/STIKEP/PPNI/JABAR/VII/2026, valid from May 3, 2026, to May 3, 2027. All participants received an explanation of the study and provided informed consent prior to data collection. Confidentiality of participant information was maintained throughout the research and data processing process.

RESEARCH RESULTS

Table 1. Changes in Blood Pressure Before and After the Intervention

Variable	T0 Mean $\pm$ SD	T2 Mean $\pm$ SD	Mean Difference	t	p-value
Systolic blood pressure (mmHg)					
Intervention	145.60 $\pm$ 11.32	140.60 $\pm$ 10.11	-5.01	-7.32	<0.001
Control	147.30 $\pm$ 13.46	145.50 $\pm$ 12.33	-1.87	-3.13	0.513
Diastolic blood pressure (mmHg)					
Intervention	95.21 $\pm$ 10.35	86.35 $\pm$ 9.32	-8.45	-9.15	<0.001
Control	92.57 $\pm$ 9.67	90.21 $\pm$ 10.33	-2.12	-2.34	0.412

*Note: SD = standard deviation; T0 = baseline; T2 = two months after the intervention.

A total of 128 patients with hypertension participated in the baseline assessment, including 64 participants in the intervention group and 64 participants in the control group. The mean age was 55.67 ± 10.65 years in the intervention group and 54.13 ± 9.25 years in the control group. The proportion of female participants was 50.0% in the intervention group and 62.5% in the control group. The mean duration of hypertension was 7.38 ± 3.55 years in the intervention group and 6.92 ± 4.11 years in the control group. The mean number of antihypertensive medications was 3.11 ± 1.54 in the intervention group and 2.76 ± 1.22 in the control group. No statistically significant differences were observed in baseline characteristics between the intervention and control groups.

Table 2. Changes in Blood Pressure Before and After Implementation

Outcome	Group	T0 Mean $\pm$ SD	T2 Mean $\pm$ SD	Change	p-value
Systolic blood pressure (mmHg)	Intervention	145.60 $\pm$ 11.32	140.60 $\pm$ 10.11	-5.01	<0.001
Systolic blood pressure (mmHg)	Control	147.30 $\pm$ 13.46	145.50 $\pm$ 12.33	-1.87	0.513
Diastolic blood pressure (mmHg)	Intervention	95.21 $\pm$ 10.35	86.35 $\pm$ 9.32	-8.45	<0.001
Diastolic blood pressure (mmHg)	Control	92.57 $\pm$ 9.67	90.21 $\pm$ 10.33	-2.12	0.412

Eldawati^{1*}, Abdul Gowi¹, Muhammad Taufik Syastra²

¹Program Studi Keperawatan, Fakultas Ilmu Kesehatan, Universitas Horizon Indonesia

²Fakultas Informatika, Universitas Horizon Indonesia

Corresponding author: *E-mail: eldawati09@gmail.com

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There were significant changes in blood pressure from baseline to two months after the intervention in the intervention group. Systolic blood pressure decreased significantly from 145.60 ± 11.32 mmHg at baseline to 140.60 ± 10.11 mmHg at T2, with a mean reduction of 5.01 mmHg ($t = -7.32$, $p < 0.001$). In contrast, the control group showed a smaller reduction in systolic blood pressure, from 147.30 ± 13.46 mmHg to 145.50 ± 12.33 mmHg, which was not statistically significant ($p = 0.513$). Similarly, diastolic blood pressure in the intervention group decreased significantly from 95.21 ± 10.35 mmHg at baseline to 86.35 ± 9.32 mmHg at T2, representing a mean reduction of 8.45 mmHg ($t = -9.15$, $p < 0.001$). In the control group, diastolic blood pressure decreased from 92.57 ± 9.67 mmHg to 90.21 ± 10.33 mmHg, but this change was not statistically significant ($p = 0.412$).

The intervention group demonstrated a greater reduction in blood pressure than the control group. Systolic blood pressure decreased by 5.01 mmHg in the intervention group, compared with 1.87 mmHg in the control group. Similarly, diastolic blood pressure decreased by 8.45 mmHg in the intervention group, compared with 2.12 mmHg in the control group. These findings indicate that the telemonitoring-based Self-Management Care intervention was associated with significant within-group reductions in both systolic and diastolic blood pressure.

Difference-in-Differences Analysis

Table 3. Difference-in-Differences Estimates Based on the Intention-to-Treat Analysis

Variable	T0–T1 DID Coefficient (95% CI)	T0–T2 DID Coefficient (95% CI)
Systolic blood pressure	2.57** (1.32–5.52)	4.34** (2.44–7.36)
Diastolic blood pressure	2.13** (1.57–4.68)	3.57** (1.89–6.60)

*Note: DID = Difference-in-Differences; CI = confidence interval; ITT = intention-to-treat. Estimates were derived from linear regression with fixed effects. * $p < 0.01$.

To further assess the effectiveness of the intervention, a Difference-in-Differences (DID) analysis was performed using an intention-to-treat (ITT) approach. The analysis compared changes in blood pressure between the intervention and control groups from T0 to T1 and from T0 to T2. The DID analysis indicated a significant difference in the change in blood pressure between the intervention and control groups. From T0 to T1, the DID coefficient was 2.57 (95% CI: 1.32–5.52) for systolic blood pressure and 2.13 (95% CI: 1.57–4.68) for diastolic blood pressure. From T0 to T2, the DID coefficient increased to 4.34 (95% CI: 2.44–7.36) for systolic blood pressure and 3.57 (95% CI: 1.89–6.60) for diastolic blood pressure. The larger DID estimates at T2 compared with T1 indicate that the difference in blood pressure trajectories between the intervention and control groups became more pronounced over the two-month implementation period. These findings suggest that the telemonitoring-based Self-Management Care model was associated with a greater improvement in blood pressure outcomes relative to standard education.

DISCUSSION

The development stages in this study indicate that the platform needs to be evaluated before being used in clinical interventions. Expert validation was used to assess the suitability of the platform's content and functions, while performance testing was used to ensure that key functions could be performed by users. Next, a usability test was conducted on 30 potential respondents to obtain feedback on ease of use, menu comprehension, ease of data input, information clarity, display, usefulness, and user satisfaction. This stage is crucial because the effectiveness of digital interventions is determined not only by the intervention content but also by the user's ability to access and use the technology. If the system is difficult to use, the intervention's benefits can be reduced even if the health content provided is appropriate. Therefore, usability is a crucial aspect in the development of digital-based health interventions. Previous research also supports the use of digital technology in hypertension management. A systematic review showed that telemonitoring and teleconsultation are widely used telehealth

Eldawati^{1*}, Abdul Gowi¹, Muhammad Taufik Syastra²

¹Program Studi Keperawatan, Fakultas Ilmu Kesehatan, Universitas Horizon Indonesia

²Fakultas Informatika, Universitas Horizon Indonesia

Corresponding author: *E-mail: eldawatiel dawati09@gmail.com

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approaches in hypertension management and can be used for blood pressure monitoring and providing remote health support (Kassavou et al., 2022; McManus et al., 2021b; Yap et al., 2024).

The implementation results showed that the use of a mobile telemonitoring application combined with self-management resulted in greater changes in blood pressure in the intervention group compared to the control group. In the intervention group, systolic blood pressure decreased from 145.6 ± 11.32 mmHg at T0 to 140.6 ± 10.11 mmHg at T2, or an average decrease of 5.01 mmHg. Diastolic blood pressure also decreased from 95.21 ± 10.35 mmHg to 86.35 ± 9.32 mmHg, with an average decrease of 8.45 mmHg. Both changes showed statistically significant results ($p < 0.001$). In contrast, the control group only experienced a decrease in systolic blood pressure of 1.87 mmHg and diastolic blood pressure of 2.12 mmHg, and these changes were not significant. These differences in change patterns suggest that the combination of telemonitoring and self-management has the potential to provide additional benefits compared to standard care. These findings are consistent with broader research evidence. A meta-analysis of digital health interventions for blood pressure management found that digital/telehealth interventions can reduce systolic blood pressure compared to usual care (Meng et al., 2023; Siopis et al., 2023).

Over a three-month intervention period, the reported systolic reduction averaged 3.21 mmHg, although there was heterogeneity between studies. These results are also consistent with a meta-analysis of telemonitoring in uncontrolled hypertension, which found significant reductions in systolic and diastolic blood pressure compared to standard care. Therefore, the blood pressure reductions found in this study support the evidence that digital technology can be a supportive component in hypertension management. The systolic reduction of 5.01 mmHg in this study is within the range of effects reported in various telehealth studies, while the diastolic reduction of 8.45 mmHg represents a substantial change. Differences in the magnitude of the effect compared with other studies may be influenced by participant characteristics, length of intervention, self-management components, intensity of monitoring, and support provided during the intervention (Baral et

al., 2023; Calderón-Anyosa et al., 2023; Yatabe et al., 2021).

One possible mechanism explaining these study results is increased patient engagement in self-monitoring of blood pressure. Patients in the intervention group not only received information but also participated in regularly measuring and recording their blood pressure through the platform. Recent evidence suggests that home blood pressure monitoring (HBPM) can provide greater blood pressure reductions than usual care. A meta-analysis of 65 studies with over 21,000 participants found a reduction in systolic and diastolic blood pressure of 3.27/1.61 mmHg in the HBPM group compared to usual care. The effect of HBPM was also stronger when combined with additional interventions such as telemonitoring or healthcare provider support (Satoh et al., 2025). These findings provide a relevant explanation for the results of this study. The platform developed did not use self-monitoring as a stand-alone intervention, but rather combined it with telemonitoring, education, and self-management support. The combination of these components likely yielded a greater effect than simply requiring patients to measure their blood pressure at home (McManus et al., 2021a; Widayastuti et al., 2025).

Management Support

In this study, telemonitoring served as a link between patients' self-management activities at home and the monitoring process during the intervention. Patients measured their blood pressure independently, and the monitoring results were then used for follow-up. This approach aligns with research showing that home blood pressure telemonitoring can aid blood pressure management. A previous meta-analysis showed that telemonitoring with automatic data transmission resulted in significant reductions in systolic blood pressure, with effects also observed in interventions using smartphone apps (Kario et al., 2023). Furthermore, telemonitoring interventions supported by healthcare professionals can also have greater effects. A meta-analysis of pharmacist-based blood pressure telemonitoring showed significant reductions in systolic and diastolic blood pressure compared to usual care (Baral et al., 2023). These research findings support the view that telemonitoring should not be positioned solely as a technology for

Eldawati^{1*}, Abdul Gowi¹, Muhammad Taufik Syastra²

¹Program Studi Keperawatan, Fakultas Ilmu Kesehatan, Universitas Horizon Indonesia

²Fakultas Informatika, Universitas Horizon Indonesia

Corresponding author: *E-mail: eldawati09@gmail.com

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transmitting blood pressure data. The added value of telemonitoring lies in its ability to support the self-management process, provide regular information, and enable follow-up on monitoring results (Katz et al., 2024; Kelly et al., 2024; Widyastuti et al., 2025).

Differences in Blood Pressure Changes Between Groups

DID analysis provided additional information regarding the intervention's effects by comparing changes in blood pressure between the intervention and control groups. At T0–T1, the DID coefficient for systolic blood pressure was 2.57 and that for diastolic blood pressure was 2.13. At T0–T2, the DID coefficient increased to 4.34 for systolic blood pressure and 3.57 for diastolic blood pressure. The increase in the DID coefficient at T2 indicates that the difference in blood pressure changes between the two groups became more pronounced after two months of intervention. This finding corroborates the results of the pre-postintervention analysis because it indicates that the changes in the intervention group were not only related to time but also differed from those in the control group. These results align with evidence that telemedicine for hypertension can provide better outcomes than clinic-based care alone, particularly when the intervention includes self-management support and healthcare professionals (Calderón-Anyosa et al., 2023; Letzelter et al., 2024; Yap et al., 2024).

Platform Development Implications

The research findings imply that developing a health application for hypertension requires integrating technological aspects with patients' behavioral needs. The developed platform not only provides blood pressure recording functionality but also integrates components that support self-management. From a development perspective, expert validation and usability testing provided a basis for ensuring the system's usability before implementation. Clinically, the implementation results demonstrated greater blood pressure changes in the group using the platform. Therefore, a phased development approach can serve as a basis for the broader development of a digital hypertension platform. For implementation in Indonesia, further development needs to consider patients' digital

literacy, device and internet access, data security, healthcare worker readiness, and system integration with healthcare services. This is crucial so that the platform can be used not only in research contexts but also has the potential to be implemented in routine healthcare (Alsaqer & Bebis, 2021; Muldoon et al., 2022; Postel-Vinay et al., 2023).

CONCLUSION

This study successfully developed and implemented a telemonitoring-based Self-Management Care Model that integrates independent blood pressure monitoring, physical activity and dietary monitoring, health education, reminders, and self-management and follow-up support. Implementation results in 128 patients with hypertension showed that the group using the platform experienced a greater reduction in blood pressure compared to the control group receiving standard education. After two months, systolic blood pressure in the intervention group decreased by 5.01 mmHg and diastolic blood pressure by 8.45 mmHg, while in the control group, the reductions were only 1.87 mmHg and 2.12 mmHg, respectively. Difference-in-Differences analysis showed a difference in blood pressure changes between the intervention and control groups, with a greater effect in the second month. Therefore, the telemonitoring-based Self-Management Care Model has the potential to be an effective approach to supporting blood pressure management and control in patients with hypertension. This model can serve as an alternative and more sustainable approach to care by integrating home monitoring, active patient involvement, and ongoing healthcare provider support.

SUGGESTION

A telemonitoring-based self-management care model can be considered a supportive approach to hypertension care to improve blood pressure monitoring and patient engagement in self-care at home. Implementation of the model requires education, regular monitoring, feedback, and follow-up from healthcare professionals. Future research is recommended to involve a larger sample size, a longer intervention period, and evaluate other outcomes, such as medication adherence, self-efficacy, self-management behavior, and quality of

Eldawati^{1*}, Abdul Gowi¹, Muhammad Taufik Syastra²

¹Program Studi Keperawatan, Fakultas Ilmu Kesehatan, Universitas Horizon Indonesia

²Fakultas Informatika, Universitas Horizon Indonesia

Corresponding author: *E-mail: eldawatiel dawati09@gmail.com

life, to more comprehensively assess the model's sustainability and effectiveness.

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Eldawati^{1*}, Abdul Gowi¹, Muhammad Taufik Syastra²

¹Program Studi Keperawatan, Fakultas Ilmu Kesehatan, Universitas Horizon Indonesia

²Fakultas Informatika, Universitas Horizon Indonesia

Corresponding author: *E-mail: eldawatiel dawati09@gmail.com

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Eldawati^{1*}, Abdul Gowi¹, Muhammad Taufik Syastra²

¹Program Studi Keperawatan, Fakultas Ilmu Kesehatan, Universitas Horizon Indonesia

²Fakultas Informatika, Universitas Horizon Indonesia

Corresponding author: *E-mail: eldawatiel dawati09@gmail.com

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