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PAPER

Safeguarding Vascular Health: Unleashing the Potential of Smartphone Early Warning Systems to Elevate Phlebitis Prevention in IV Infusion Therapy

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ABSTRACT

Intravenous (IV) infusion is a pervasive medical intervention, administered to approximately 90% of hospitalized patients. Phlebitis, characterized by inflammation of the veins resulting from infusion, stands as a prevalent complication, ranking fourth among hospital-acquired infections globally. This research investigates the efficacy of a Smartphone Early Warning System (EWS) display in mitigating the incidence of phlebitis within the Safa treatment room at Aisyiyah Hospital. Employing a pre-experimental research design with a Static-group Comparison approach, 16 respondents were allocated to treatment and control groups. The Mann-Whitney Test, a statistical analysis, unveiled a significant difference (P Value = 0.001 < 0.05) in phlebitis incidence between the treatment group, utilizing the Smartphone EWS display, and the control group, which relied on conventional monitoring methods. Notably, the average rank of phlebitis incidence in the control group (21.12) exceeded that in the treatment group (9.78). This study sheds light on the potential of the Smartphone EWS display to curtail phlebitis during infusion, emphasizing its role in advancing nursing care quality through real-time monitoring and early prevention strategies.

KEYWORDS

infusion, early warning system, phlebitis, IoMT, mobile technology

1 INTRODUCTION

Technological growth has fundamentally transformed sectors like government, education, and healthcare, serving as a primary driver in modernizing public services, revolutionizing learning methods, and reshaping healthcare approaches [1]–[4]. The implementation of health information systems, advanced medical devices, and the utilization of health mobile applications provides efficient support in the diagnosis, treatment, and management of health. These innovations not

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only enhance the quality of healthcare services but also offer improved monitoring capabilities for patients' conditions [5], [6].

In contemporary medical and nursing practices, intravenous (IV) infusion stands as a cornerstone, with approximately 90% of hospitalized patients relying on this vital modality for diverse medication administration [7]. However, the prevailing method of manually monitoring infusion fluid in hospitals, involving periodic checks by medical personnel relying on clocks, raises significant concerns regarding accuracy and vulnerability to errors [7]. This approach becomes particularly precarious given the potential complications, notably bloodstream infection, or phlebitis, ranking as the fourth most common infection acquired by patients during hospital stays [8].

Observations and interviews conducted at a hospital in Pariaman City, West Sumatra, revealed a noteworthy association between prolonged treatment duration and increased phlebitis incidence. Among 20 patients treated, 13 developed phlebitis, and treatment exceeding five days escalated the incidence by nearly 90% [9]. The severity of complications is exemplified by the potential formation of blood clots in the infusion tube, posing a life-threatening risk of pulmonary embolism as the clot travels through the bloodstream and obstructs capillaries in the lungs [10].

The recurrent reliance on manual infusion monitoring underscores the need for a transformative approach. The prevalence of phlebitis, often attributed to inadequate venous assessment [11], [12], necessitates concerted research and health promotion efforts. Recognizing the imperative for innovation, an EWS for patient infusion, explicitly leveraging the Internet of Things (IoT) infusion detection and sensors for monitoring the smoothness of infusion drops, emerges as a proactive solution [13–15].

EWS, as a critical component, not only assesses patients' health risks at an early stage but also plays a pivotal role in preventing complications, thereby expanding the horizons of healthcare. By addressing the limitations of manual monitoring, the proposed EWS offers a swift and effective response to mitigate the risks associated with bloodstream infections such as phlebitis. This paradigm shift aligns with the evolving landscape of healthcare, emphasizing the potential of technology-driven solutions to enhance patient safety and optimize healthcare delivery.

This paper posits a groundbreaking contribution to the field through the proposition of a Smartphone EWS, integrating sensors and Internet of Things (IoT) technology. This innovative system aims to revolutionize infusion monitoring, providing real-time data on the smoothness of infusion drops, thus mitigating the risks associated with phlebitis. The remainder of this manuscript delves into the empirical investigation of the proposed EWS, exploring its efficacy, practical implications, and broader ramifications within the context of patient care.

2 RELATED WORK

Patients staying in a hospital for a long time have a high risk of impaired skin integrity and blood vessel damage, which can be overcome early by providing appropriate and correct treatment [16]. Manual infusion monitoring has limitations for nurses in providing nursing care. Smartphone-based infusion monitoring prevents phlebitis by enabling remote, precise, and fast monitoring and stopping of infusion systems. This system uses Android-based telemetry to control and manage automatic infusions, resulting in more effective and accurate monitoring and stopping of infusions. This system's development involves using electronic components such as light sensors, keypads, WiFi modules, servo motors, and GSM modules, which are controlled by an Arduino Mega 2560. This system also uses an LCD, website, and Android application to display detection data. Test measurements of this system show that the

average error in the infusion drip sensor is 3.5% and 2.5%, while the infusion rate stop system and device notification system did not experience problems. The development of a smartphone use system provides convenience, accuracy, and practicality [17].

3 RESEARCH FRAMEWORK

This study adopts a pre-experimental research design with a Static-group Comparison approach to investigate the impact of the EWS on phlebitis incidence during IV infusion. By focusing on a treatment group utilizing the EWS Display Smartphone and comparing it to a control group without this technological intervention, the research design aims to provide a comprehensive understanding of the system's effectiveness.

This study's central research question is: "Is there a discernible effect of a smooth infusion drip with the EWS Display Smartphone on the incidence of phlebitis in the Safa treatment room of Aisyiyah Hospital?" This formulation sets the stage for a nuanced exploration into the transformative potential of the Smartphone EWS in mitigating phlebitis during IV infusion, contributing valuable insights to healthcare technology.

The hardware design of the Infusion Fluid Monitoring System, depicted in Figure 1, intricately integrates the EWS Display Smartphone. This hardware plays a pivotal role in capturing real-time data on infusion rates, ensuring a seamless and technologically advanced monitoring process. The selection of a microcontroller further strengthens the system's capabilities. Microcontrollers are chosen for their ability to provide precise control and rapid data processing. The microcontroller facilitates seamless integration between various system components, including sensors and the EWS Display Smartphone, by serving as the central processing unit. Its efficient data acquisition and processing capabilities enhance the accuracy and reliability of the monitoring system. Complementing this, Figure 2 provides a detailed System Diagram Block, offering a comprehensive overview of the integrated sensors, Smartphone EWS, and the connections within the system. This illustrates the systematic approach employed to monitor the smoothness of infusion drops and prevent the onset of phlebitis.

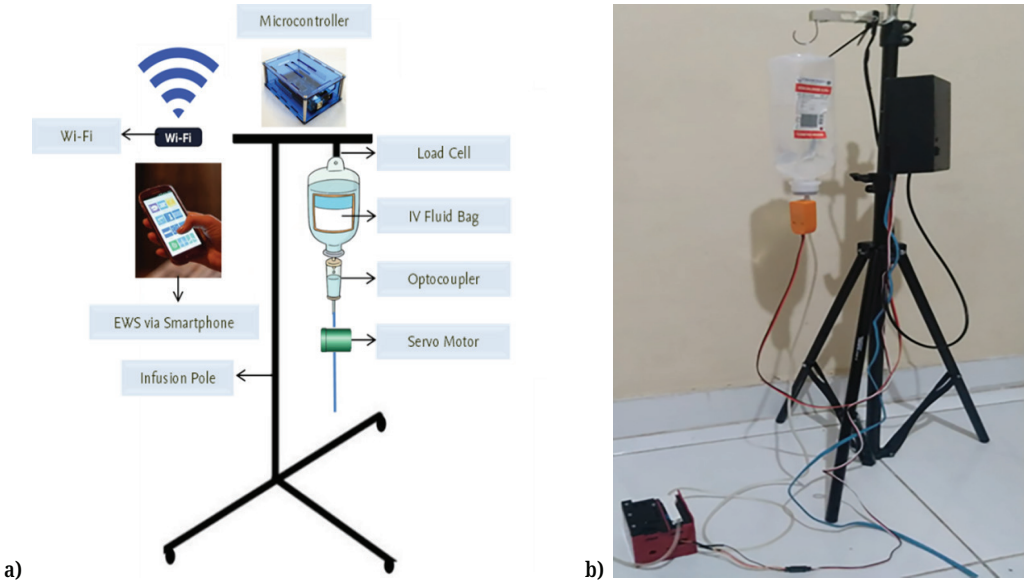

Fig. 1. Hardware Design of Infusion Fluid Monitoring System (a); prototype (b)

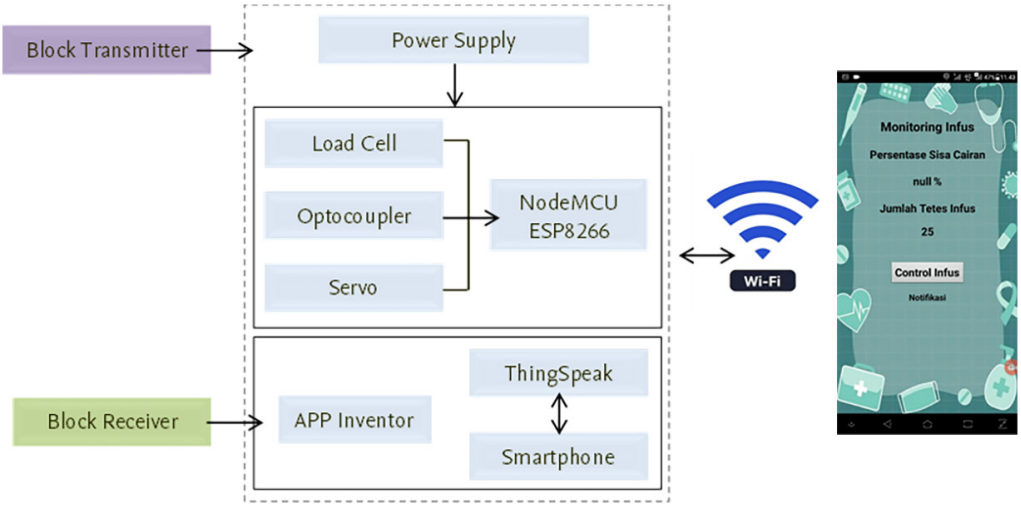

Fig. 2. System Diagram Block

4 RESEARCH METHODS

In the pursuit of scientific rigour, this study employs a pre-experimental research method coupled with a Static-group Comparison approach. This methodological choice allows a meticulous examination of the cause-and-effect relationship by subjecting a treatment group to a specific intervention and comparing its outcomes with a control group [8]. Such an approach is fundamental to unravelling the nuanced impact of interventions, particularly in healthcare settings.

4.1 Sampling

The research is centered on a particular population: all patients receiving intravenous (IV) infusion within the Safa treatment room at Aisyiyah Hospital. Understanding the importance of obtaining a representative sample, the study employs incidental sampling. This method involves selecting individuals encountered by the researcher who meet the criteria to serve as potential subjects based on their appropriateness as data sources. In other words, patients who happen to be present in the Safa treatment room and are undergoing IV infusion are included in the study without any specific pre-selection process. This approach aims to capture a diverse range of patients and situations encountered in real-world clinical settings, providing a comprehensive understanding of IV infusion practices and outcomes in this particular hospital environment [9].

The sample size, comprising 16 individuals, is distributed equally between the control (8 participants) and intervention (8 participants) groups. Considering the practical constraints of conducting research within a hospital setting, a sample size of 16 participants was deemed feasible and appropriate. The selection criteria for participants are meticulously outlined to ensure a targeted and homogenous sample. Inclusion criteria encompass general characteristics, such as a willingness to participate, undergoing infusion, and receiving a singular injection of antibiotics. On the contrary, exclusion criteria are established to eliminate subjects who do not meet specific conditions, such as unwillingness to participate or undergoing excessive infusion therapies [18].

4.2 Inclusion and exclusion criteria

In establishing inclusion criteria, the study delves into the fundamental characteristics of research subjects within the defined population. The willingness of patients to participate actively in the study is a critical factor in ensuring that the collected data is robust and reflective of the targeted population. Furthermore, including patients undergoing infusion and receiving a specific antibiotic injection narrows the focus to a specific cohort, enhancing the study's precision.

Conversely, exclusion criteria are designed to refine the sample further. Patients unwilling to participate for specific reasons are excluded, ensuring a cohort of participants who actively engage with the study. Additionally, the limitation on the number of infusion therapies mitigates the risk of confounding variables, contributing to the study's internal validity [19]. This comprehensive research methodology lays the groundwork for a rigorous investigation into the impact of the intervention, adhering to established scientific principles and ensuring the reliability and validity of the study's findings.

5 RESULTS AND DISCUSSION

5.1 Demographic characteristics of respondents in the treatment group

The demographic characteristics of respondents in the treatment group were thoroughly analyzed to understand the study population comprehensively. As depicted in Figure 3, the age distribution of respondents shows a significant concentration (50%) within the 20–35 age bracket. This age group represents a substantial portion of the treatment group, indicating the relevance of this age range in the study context. Understanding the age distribution among respondents is vital as it helps contextualize the findings and assess any potential age-related factors that may influence the study outcomes.

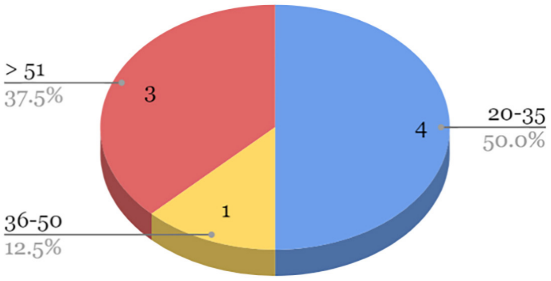

Fig. 3. Distribution of treatment group respondents by age

Table 1 presents the gender distribution among respondents in the treatment group, revealing that 62.5% of the participants are female. This indicates a higher representation of female respondents than male respondents in the treatment group.

Table 1. Gender distribution of respondents in the treatment group

Gender	Number of Respondents	Percentage (%)
Woman	5	62.5%
Man	3	37.5%
Total	**8**	**100%**

Table 3 presents the incidence of phlebitis within the treatment group. It indicates that among the total respondents in this group, 25% encountered phlebitis as a complication. Specifically, 2 out of 8 respondents experienced phlebitis. On the contrary, the majority of respondents in the treatment group, constituting 75%, did not experience phlebitis. This accounts for 6 out of 8 individuals unaffected by the complication. The table provides valuable insight into the prevalence of phlebitis among participants in the treatment group, indicating that the incidence rate is lower compared to the control group (25% vs. 62.5%). Such data aids in understanding the efficacy of the treatment intervention in potentially reducing the occurrence of phlebitis within the study population.

Table 2. Incidence of phlebitis in the treatment group

Phlebitis Incident	Number of Respondents	Percentage (%)
Phlebitis	2	25%
Not Phlebitis	6	75%
Total	**8**	**100%**

These demographic insights provide a foundational understanding of the study's participant profile, setting the stage for a thorough analysis of the impact of the EWS Display Smartphone on the incidence of phlebitis.

5.2 Demographic characteristics of respondents in the control group

The analysis of the control group respondents' characteristics aimed to assess the influence of the EWS Display Smartphone on the incidence of phlebitis. Figure 4 illustrates the age distribution of the control group respondents, indicating a significant concentration of 53% within the 20–35 age range. This concentration suggests that a considerable portion of the control group falls within this age bracket. Understanding the age distribution among the control group respondents is essential as it provides insights into the demographic composition of the study population. It helps contextualize the findings related to phlebitis incidence and allows for a more nuanced interpretation of the impact of the EWS Display Smartphone on different age groups within the control group.

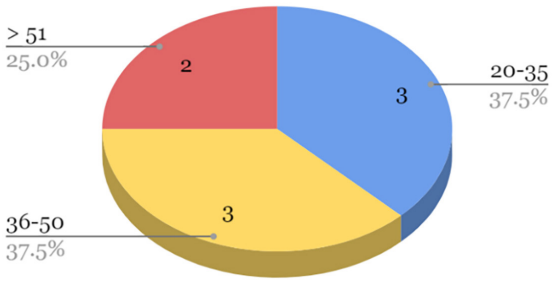

Fig. 4. Distribution of control group respondents by age

Table 3 presents the gender distribution within the control group. It illustrates that out of the total respondents in this group, 62.5% are female participants, whereas 37.5% are male. This distribution sheds light on the composition of the control group in terms of gender, indicating a higher representation of females than males.

Table 3. Gender distribution of control group respondents

Gender	Number of Respondents	Percentage (%)
Woman	5	62.5%
Man	3	37.5%
Total	**8**	**100%**

Table 4 provides an overview of the occurrence of phlebitis within the control group. It reveals that out of the total respondents in the control group, 62.5% experienced phlebitis as a complication. Precisely, 5 out of 8 respondents encountered phlebitis, constituting the majority of cases. Conversely, 37.5% of respondents did not experience phlebitis, with only 3 out of 8 individuals unaffected by this complication. This table helps understand the prevalence of phlebitis among the participants in the control group, highlighting its significance as a potential issue within the study population.

Table 4. Incidence of phlebitis in the control group

Phlebitis Incident	Number of Respondents	Percentage (%)
Phlebitis	5	62.5%
Not Phlebitis	3	37.5%
Total	**8**	**100%**

Table 5. Statistical analysis of phlebitis incidence

Category	Mean Rank	Sum of Rank	P-Value	n
Treatment Group	9.78	163.00	0.001	8
Control Group	21.12	302.00	0.001	8

Table 5 presents the Mann-Whitney Test results, demonstrating a significant difference between the treatment and control groups (P Value = 0.001 < 0.05). The average incidence of phlebitis in the control group (21.12) surpasses that of the treatment group (9.78), supporting the acceptance of the alternative hypothesis (Ha) that the EWS Display Smartphone effectively reduces phlebitis incidence.

The higher occurrence of phlebitis in the control group, particularly among female participants, aligns with existing literature associating gender, age, and the patient's basic condition with phlebitis incidence. Notably, the age range of 51–61 years emerges as a significant risk factor, consistent with previous studies [20], [21]. Furthermore, the concentration of chemical phlebitis among control group respondents, primarily linked to antibiotic infusion, underscores the importance of proper drug preparation and administration.

This finding suggests a potential link to previous research indicating that intravenous therapy might harm the venous endothelium, increasing the risk of phlebitis. Additionally, maintaining stable drip rates is crucial to prevent complications, highlighting the efficacy of early monitoring facilitated by the EWS smartphone display [22], [23]. In conclusion, the results confirm that the EWS Display Smartphone significantly reduces the incidence of phlebitis compared to manual monitoring.

6 CONCLUSIONS AND FUTURE WORK

In conclusion, the findings of this study highlight significant disparities in phlebitis incidence associated with the adoption of smartphone display EWS infusion monitoring, as opposed to traditional manual methods. The successful integration of

the Early Warning Smartphone display system represents a notable advancement, not only streamlining the operational workflow for nursing staff but also playing a pivotal role in proactively mitigating risks and complications inherent in infusion therapy. By providing real-time monitoring and prompt detection of potential issues, the EWS empowers healthcare providers to intervene swiftly, thereby minimizing adverse events and enhancing patient safety throughout the infusion process.

Moving forward, future research in this domain should adopt a comprehensive approach to further refine and expand the capabilities of the EWS. Efforts could focus on optimizing the technological interface to enhance usability and functionality, ensuring seamless integration into existing healthcare protocols. This may involve refining the user interface design, implementing intuitive features for data interpretation, and leveraging artificial intelligence algorithms to provide predictive insights into infusion-related complications. Additionally, exploring the scalability and adaptability of the system to different healthcare settings and patient demographics would be crucial for maximizing its impact across diverse clinical environments.

Moreover, longitudinal studies assessing the long-term impact of the EWS on patient outcomes and healthcare resource utilization are warranted. These studies can provide valuable insights into the sustained effectiveness of the system over time, identify areas for improvement, and inform evidence-based decision-making in healthcare delivery. Economic evaluations can complement these efforts by quantifying the cost-effectiveness of implementing the EWS and demonstrating its value proposition to healthcare organizations and policymakers.

In essence, the findings of this study lay a solid foundation for future research aimed at further enhancing the technological solutions available for infusion monitoring. Through the adoption of innovation and harnessing cutting-edge technologies, we can persistently enhance patient safety, streamline healthcare delivery processes, and cultivate ongoing enhancements in patient care practices, not only within infusion therapy but also across broader healthcare domains.

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