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The Effect of Smart Bed on Pressure Ulcer Prevention among Patients with Stroke in West Java, Indonesia

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ABSTRACT

Background: Stroke is the third leading cause of mortality in Indonesia, significantly contributing to comorbidities and healthcare costs. The integration of the Internet of Things (IoT) in healthcare has the potential to improve patient care by automating patient movement and vital sign monitoring. Objective: This study aims to evaluate the effectiveness of an IoT-enabled smart bed system in preventing pressure ulcers among stroke patients by automating patient repositioning and monitoring key physiological parameters. Methods: A quasi-experimental study was conducted in a private hospital in West Java, Indonesia, involving 30 stroke patients divided into an intervention group (n=15) receiving the smart-bed system and a control group (n=15) receiving conventional care. The Braden Scale was used to assess pressure ulcer risk. Data collection included pre-test, post-test, and follow-up assessments over a one-month intervention period. Repeated Measures ANOVA was used to analyse differences between groups. Results: The intervention group showed significant improvements in sensory perception (+8.23 points, p=0.001, eta=0.31), humidity (+8.76 points, p=0.002, eta=0.28), activity (+9.12 points, p=0.001, eta=0.37), mobilisation (+8.76 points, p=0.002, eta=0.33), nutrition (F=7.66, p=0.001, eta=0.35), and friction (F=8.22, p=0.001, eta=0.30). The control group exhibited no significant changes across these variables. Conclusion: The IoT-enabled smart bed significantly improved factors related to pressure ulcer prevention, reducing the burden on caregivers and healthcare providers. This technology offers a promising solution for enhancing patient care and reducing pressure ulcer incidence among stroke patients.

Keywords: Automated Repositioning; Healthcare Technology; Internet of Things; Pressure Ulcers; Patient Care; Smart Bed; Stroke

INTRODUCTION

Stroke ranks as the third most common cause of mortality in Indonesia and strongly influences the prevalence of comorbidities and the expenses associated with treatment. In 2018, the incidence of stroke rose by 10.9% compared to the previous year, representing a 3.9% rise from 2013 (Agency of Health Research and Development (Indonesia). (2018). Notably, stroke patients are no longer exclusively older individuals but have manifested in many stages of life, beginning at the age of 35. The likelihood of experiencing a stroke rises at the age of 45, with an incidence rate of 14.2% (Kemenkes, 2018). Prior research findings indicate that over 50% of stroke patients develop pressure ulcers, leading to higher death rates within 30 days after a stroke episode. Pressure ulcers are medical injuries resulting from prolonged application of pressure. Furthermore, the expenses associated with treating pressure ulcers are exorbitant. For instance, in the United States, the cost of treating pressure ulcers ranges from $500 to $70,000 per patient annually (Centres for Medicare & Medicaid Services, 2009; Improvement, 2015).

Effective patient repositioning is crucial for both preventing and treating pressure ulcers (also known as decubitus ulcers). However, the physical demands of repositioning patients every two hours can lead to significant challenges for caregivers, including nurses and family members (Andersen *et al*., 2019). Recent

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advancements have led to the development of assistive technologies aimed at preventing pressure ulcers. For instance, wearable sensors have been utilised to enhance patient repositioning by allowing staff to quickly identify which patients need to be turned (Aljohani & Pascua, 2019). However, it's important to note that while these sensors aid in monitoring, nursing staff still need to physically turn patients and incorporate other evidence-based interventions to ultimately prevent pressure injuries. Additionally, a review of assistive devices for the prevention of pressure ulcers highlighted the challenges caregivers face with manual repositioning and emphasised the need for innovative solutions to alleviate the physical demands on caregivers (Gillespie *et al*., 2021). Implementing such technologies can potentially reduce the physical strain on caregivers and improve patient outcomes by ensuring timely and effective repositioning

Healthcare institutions are increasingly integrating robotic systems and sensor-based technologies to improve service quality and efficiency. Innovations such as robotic-assisted mobility devices, manual patient transfer tools, and automated force beds for sheet manipulation have been developed. Additionally, specialised beds, including air mattresses, alternating pressure mattresses (APM), and lateral rotation mattresses, have been designed to prevent decubitus ulcers (Eilbeigi *et al.*, 2017). However, existing solutions remain energy-intensive and inefficient. Notably, no current mattress system autonomously moves patients every two hours while simultaneously monitoring vital signs such as blood pressure, pulse, temperature, and respiration.

While various commercial devices aid in preventing decubitus ulcers, most rely on manual tools for patient transfer and sheet manipulation. Air mattresses, alternating pressure mattresses (APM), and lateral rotation mattresses remain the most widely used and efficient solutions. These advanced mattresses regulate temperature, maintain humidity, facilitate leg and head movement, and rotate to prevent prolonged pressure on a single area (Fan & Lu, 2020; Gaspar *et al*., 2022; Matar, Lina & Kaddoum, 2019; Parisod *et al*., 2022; Shi *et al*., 2021; Singh, Gupta & Chanda, 2021; Smith, 2019; Tachibana et al., 2016). A prior study by Eilbeigi *et al*. (2017) developed a non-grasping force bed equipped with sensors to monitor patient conditions. However, this system was not fully automated. Sensors play a critical role in monitoring bed operations, allowing real-time adjustments based on patient positioning and applied forces. Furthermore, these beds provide valuable data for studying the conditions that lead to decubitus ulcers. Other studies have introduced intelligent beds, such as the MedBed (Kassem *et al*., 2017), designed to reduce the workload on healthcare staff (Kajol *et al*., 2019). Given the current shortage of hospital personnel, enabling patients to control bed functions autonomously is crucial. MedBed allows voice-activated commands, making it particularly beneficial for individuals with limited mobility, including those unable to perform manual or finger movements (Kajol *et al*., 2019). By integrating IoT and automation, smart beds have the potential to revolutionise patient care, enhance efficiency, and reduce the burden on healthcare professionals

Recent advancements in smart health technologies have demonstrated the utility of smart beds in improving patient care, monitoring physiological parameters, and ensuring timely interventions (Zhang, Zhao & Liu, 2023; Lee & Park, 2023). The integration of IoT enhances real-time data acquisition and transmission, facilitating remote monitoring and improved decision-making processes (Kim *et al*., 2023). Furthermore, the use of AI-driven algorithms within smart-bed systems can assist in detecting abnormalities, predicting adverse events, and supporting healthcare providers in clinical decision-making (Cheng, Huang & Lin, 2023; Mansouri *et al*., 2024).

A smart bed integrates both hardware and software components, including a patient monitoring system designed along a system architecture. The development of this comprehensive system consists of three primary components: the smart bed system, the patient monitoring system, and the IoT-based application. The objective of this research is to evaluate the efficacy of an internet of things-based smart bed in preventing pressure ulcers in stroke patients.

METHODOLOGY

Study Design and Setting

The study used is a quasi-experimental design carried out in a Private Hospital in West Java, comprising two groups: an intervention group and a control group. The intervention group was provided with a smart bed, while the control group will be provided with a conventional mattress.

Design and Development

This study consists of three development phases. The first phase focuses on the design and construction of a remotely controlled smart mattress. This mattress is integrated with sensors that continuously measure the patient's weight, temperature, and humidity in real time. Based on predefined criteria set by the control centre, a microcontroller adjusts the mattress's condition accordingly. The second phase involves the design and development of a monitoring system capable of tracking patient conditions through vital signs, including body temperature, humidity, oxygen levels, pH, heart rate, and blood pressure. These physiological parameters are collected by sensors connected to a microcontroller, which then transmits the data online to an Internet of Things (IoT) system for real-time monitoring. The third phase centres on the development of an IoT-based software application with a robust database management system (Taryudi, Lindayani & Darmawati, 2022). This application facilitates remote control and continuous monitoring of the smart bed system via smart digital devices, ensuring efficient and real-time patient management (Taryudi *et al.*, 2023).

Intervention Protocol

The intervention programme is designed to span one month, during which participants in the intervention group are provided with a smart bed. Throughout this period, a total of 12 structured sessions are implemented, with three sessions conducted each week. These sessions are systematically arranged to ensure adequate exposure to the intervention while allowing participants sufficient time to adapt to the smart bed's features and benefits.

Each session is carefully guided to optimise participant engagement and adherence to the intervention. Participants receive comprehensive instructions on the functionality of the smart bed, including how to utilise its features effectively to enhance their well-being. The sessions focus on both the physiological and psychological aspects of the intervention, integrating strategies that promote relaxation, comfort, and potential therapeutic effects. Regular monitoring and feedback mechanisms are incorporated to assess participant responses and address any technical or usability challenges they may encounter.

The implementation of the sessions ensures a gradual progression in the adaptation process, enabling participants to experience the benefits of the smart bed over time. Health professionals or trained facilitators are available to provide support, ensuring that participants follow the recommended usage guidelines. This structured approach allows for consistency in the intervention's application and contributes to the reliability of its outcomes.

Upon completing the one-month intervention, a post-test evaluation is conducted immediately for both the intervention and control groups. This assessment aims to measure the immediate effects of the intervention, capturing changes in relevant outcome variables. Additionally, a follow-up evaluation is carried out one month after the intervention concludes. This secondary assessment helps determine the sustainability of the intervention's impact, offering information about whether the effects persist beyond the active intervention period. The comparison of post-test and follow-up results between the two groups enables a comprehensive evaluation of the smart bed's effectiveness.

Sample

Population in this study consists of stroke patients. The technique used a convenience sampling. Inclusion criteria were patients diagnosed with stroke, aged above 65 years old, with a duration of disease above 5 years, with a moderate braden scale was moderate, without complications. Exclusion criteria were patients with cognitive and mental disorders; the range of motion was 1 to 2 for all extremities. Sample size was calculated using G-Power Software Version 3.1.6 with an F test assumption of $\alpha = 0.05$, effect size = 0.20 (medium effect) (Faul *et al*., 2007), power level = 0.80. Consequently, the total sample size to be recruited is 15 for each group.

The participants were also notified of their entitlement to refuse participation or withdraw voluntarily before or during the research without incurring any repercussions. Before collecting data, the researchers provided a comprehensive explanation to potential volunteers about the significance of their participation in relation to the existing circumstances to avoid the Hawthorne effect. Participant confidentiality was maintained, and data security measures were used.

Instruments

Evaluation of pressure ulcer risk using the Braden scale. The Braden scale is a specific scale or approach used to evaluate the susceptibility to pressure ulcers in individuals who may experience extended periods of bed rest. Barbara Braden developed the Braden scale in 1987 specifically for the domain of nursing homes in the United States. Six subscales comprise the Braden scale for assessing the risk of pressure ulcers: Sensory Perception, Moisture, Activity, Mobilisation, Nutrition, and Friction (Braden & Bergstrom, 1987). Evaluation of the Braden scale score using the following criteria: mild risk indicated by a score between 15 and 23, moderate risk indicated by a score between 13 and 14, severe risk indicated by a score between 10 and 12, and very severe risk indicated by a score below 10.

Data Collection

Preliminary approval for the research was obtained from the Institutional Review Board in Bandung before collecting data. Two research assistants aided in the recruitment of participants, and the clinic administration was contacted to deliberate on the study's goals, methodologies, and ethical clearances. Prior to participation, eligible participants were provided with a thorough elucidation of the study's goals, procedures, and ethical approval. Participants were allocated into two groups: a control group and an intervention group. The intervention group is provided with a smart bed for the duration of one month. The intervention programme consisted of 12 sessions, dispersed across 3 sessions each week. Post-test evaluation is carried out immediately after the intervention and one month later for both groups.

Data Analysis

On a modified intention-to-treat basis, the change in study outcome in both groups was analysed, with participants who have completed at least one post-baseline assessment included. The study employed a Repeated Measures ANOVA to examine the disparity in outcomes between two groups after the implementation of an intervention. The data was analysed using SPSS version 22 for Windows. A significance level of 5% is employed when conducting between-group comparisons and analysing interaction terms.

Ethical Consideration

This research received ethical approval from the Ethics Committee of STIKep PPNI Jawa Barat, Indonesia with reference number III/076/KEPK/STIKep/PPNI/Jabar/III/2024 on 1st March, 2024.

RESULTS

Table 1 shows the demographic comparison between the intervention and control groups. Of 15 patients in the intervention group, the mean age was 66.47 (SD=2.55), 66.67% were Muslim, and 86.67% were living with family. While, in the control group, their mean age was 66.31 (SD=2.39), 73.33% were Muslim, and 93.33% lived with family. No significant differences between the intervention and control groups in demographic characteristics.

Table 1: Demographic Comparison between Intervention and Control Group (n=30)

Variables	Intervention Group	Control Group	*p*-value
	n=15(%)	n=15(%)	
Age, Mean ± SD	66.47±2.55	66.31±2.39	0.256
Education Level			
In-school	7 (46.67)	8 (54.33)	0.133
Out-school	8 (54.33)	7 (46.67)	
Religion			
Muslim	10 (66.67)	11 (73.33)	0.279
Non-Muslim	5 (33.33)	4 (26.67)	
Living with Family			0.112
Yes	13 (86.67)	14 (93.33)	
No	2 (13.33)	1 (6.67)	

Table 2 showed that in the intervention group, the sensory perception score was increased at follow-up by 8.23 points with a *p*-value of 0.001 and an effect size (eta=0.31). Humidity also increased significantly at follow-up for 8.76 points with a *p*-value of 0.002 and an effect size (eta=0.28). Then, activity and mobilisation increased significantly at follow-up for 9.12 points with a *p*-value of 0.001 and an effect size (eta=0.37) and 8.76 points with a *p*-value of 0.002 and an effect size (eta=0.33), respectively. There was also significant improvement in nutrition at follow-up with $F = 7.66$, p-value = 0.001, Eta = 0.35. Lastly, friction also improves at follow-up with $F = 8.22$, p-value = 0.001, Eta = 0.30. However, in the control group, there was no significant improvement in terms of sensory perception, humidity, activity, mobilisation, nutrition, and friction.

Table 2: Dependent Variables Change During Three Phases of Study in the Control and Intervention Groups

Group	Variables	Mean ± SD			*F*	*p*-value	Eta
		Pre-test	Post-test	Follow Up			
Intervention Group	Sensory perception	13.78±1.22	14.22±1.15	15.56±1.12	8.23	0.001	0.31
	Humidity	13.62±1.21	14.25±1.22	15.65±1.25	8.76	0.002	0.28
	Activity	13.41±1.43	14.57±1.12	15.72±1.17	9.12	0.001	0.37
	Mobilization	13.22±1.15	13.82±0.97	15.65±1.25	8.76	0.002	0.33
	Nutrition	13.25±1.22	13.51±1.12	14.22±1.14	7.66	0.001	0.35
	Friction	13.57±1.12	13.14±0.89	15.27±1.33	8.22	0.001	0.30
Control Group	Sensory perception	13.85±1.23	13.82±0.97	13.76±1.04	0.79	0.321	0.12
	Humidity	13.62±1.33	13.51±1.12	13.68±1.10	0.85	0.115	0.07
	Activity	13.38±1.76	13.14±0.89	13.25±0.91	0.75	0.241	0.09
	Mobilization	13.85±1.23	12.56±1.12	13.02±1.45	0.45	0.276	0.13
	Nutrition	13.62±1.33	12.65±1.25	13.22±1.56	0.78	0.104	0.08
	Friction	13.38±1.76	13.72±1.17	13.25±0.94	0.88	0.145	0.10

DISCUSSION

This study found that implementing a smart bed significantly reduces the risk of pressure ulcers by improving patient care through autonomous repositioning. Unlike conventional four-way fold care beds, the proposed smart medical bed features an automatic mode that eliminates the need for manual repositioning, especially at night. This functionality is particularly beneficial for bedridden patients or those with limited mobility, as the bed automatically rotates the patient every two hours. By distributing pressure evenly across different body areas, the smart bed minimizes the risk of pressure injuries.

Several smart medical beds have been developed, including the Novel Medical Bed (El Jaouhari *et al*., 2019), the 4-Way Fold Care Bed (Eilbeigi *et al*., 2017), the Freedom Bed by ProBed Medical (Kassem *et al*., 2017), and the MedBed (Taryudi, Lindayani & Darmawati, 2022). However, most of these still require substantial carer involvement. In contrast, the proposed smart bed reduces carer workload by integrating automated repositioning, real-time vital sign monitoring, and adjustable mobility settings. Unlike the 4-Way Fold Care Bed (Tawfik *et al*., 2018), which requires extensive manual support and additional cushioning, the smart bed operates efficiently with minimal maintenance and does not require external modifications.

In automatic mode, the bed remains stationary for two hours before rotating the patient to a new position, as recommended by international healthcare guidelines (Centres for Medicare & Medicaid Services, 2009; Kemenkes, 2018). This feature is particularly advantageous during nighttime hours, as it eliminates the need for caregivers to wake up every two hours to reposition the patient. Figure 5 illustrates the head positioning mechanism of the smart bed.

Currently, only a few smart medical bed solutions are available, including the Novel Medical Bed (El Jaouhari *et al*., 2019), the 4-Way Fold Care Bed (Eilbeigi *et al*., 2017), the Freedom Bed by ProBed Medical (Kassem *et al*., 2017), and the MedBed (Taryudi, Lindayani & Darmawati, 2022). However, most of these do not cater to patients with conditions such as locked-in syndrome. The proposed smart bed addresses this gap by integrating IoT-based self-management features, allowing patients with some mobility to control bed adjustments independently, reducing reliance on nursing staff.

Unlike the 4-Way Fold Care Bed (Tawfik *et al*., 2018), which requires significant carer intervention and additional cushions to assist the patient, the proposed smart bed is designed for minimal maintenance and does not require external pillows. Additionally, caregivers can manually rotate the bed in either direction to alleviate strain on the patient's back. The bed also integrates a movable lavatory system, which can be controlled via an Android tablet connected to an Arduino microcontroller through Bluetooth. The smart bed operates in two modes: Manual Mode – Allows caregivers to control the bed's rotation and Automatic Mode – Rotates the patient every two hours without carer intervention. Load cells distributed across the bed measure the patient's weight, enabling precise calculations for the rotation angle. Additionally, the bed is equipped with sensors that monitor vital signs such as body temperature, heart rate, airflow, and electrocardiography signals.

Sensory perception plays a crucial role in preventing pressure ulcers. Smith (2019) found that patients with reduced sensory perception are at a higher risk of developing pressure injuries due to prolonged pressure on specific body areas. The smart bed addresses this issue by using load-distributing sensors that ensure even weight distribution, reducing localised pressure on bony prominences. Compared to traditional beds that rely on carer intervention, this proactive approach aligns with recent research on pressure ulcer prevention strategies (Zuniga et al., 2024). Maintaining appropriate skin moisture levels is essential to prevent maceration and skin breakdown. Excess moisture caused by incontinence or perspiration accelerates skin degradation (Elsayed et al., 2015). To address this, the smart bed incorporates humidity sensors that monitor moisture levels and activate ventilation mechanisms when needed, preventing excessive humidity buildup around the patient's body. This feature is superior to traditional care beds, where caregivers must manually assess and manage moisture concerns.

Adequate nutrition is another key factor in maintaining skin integrity and preventing pressure ulcers (Banks *et al.*, 2023). While the smart bed does not directly influence dietary intake, it enhances patient comfort and reduces stress, which can positively impact overall well-being and appetite. Additionally, the bed's weight-monitoring sensors provide real-time feedback on patient weight trends, enabling caregivers to detect nutritional deficiencies and intervene accordingly. Friction and shear forces contribute to skin breakdown, particularly in immobile patients (Chien & Tsai, 2023). The smart bed minimizes friction by adjusting positions smoothly without abrupt movements, unlike traditional care beds that require manual adjustments, which increase the risk of friction-related injuries. This study supports previous research indicating that automated bed systems effectively reduce shear forces and enhance patient comfort (Noreen *et al*., 2023).

The proposed clever medical bed, with its innovative automatic mode, has significant clinical implications for reducing the risk of developing pressure ulcers, particularly in bedridden patients. Pressure ulcers, a common and costly healthcare challenge, often arise from prolonged immobility, placing patients at risk of skin breakdown and associated complications. By automating patient repositioning, especially during nighttime hours, the clever medical bed eliminates the need for caregivers to manually reposition patients every two hours. This not only enhances patient comfort by ensuring uninterrupted rest but also reduces the physical strain and time demands on caregivers and healthcare staff. Additionally, the dual functionality of the bed—offering both manual and autonomous operation—provides flexibility for use in various clinical and home care settings. The manual mode allows for precise adjustments to meet individual patient needs, while the autonomous mode ensures consistent care without constant supervision. This innovation can lead to better clinical outcomes, such as lower rates of pressure ulcer incidence, reduced healthcare costs associated with wound care, and improved overall quality of life for patients. It also addresses staffing challenges in healthcare facilities by decreasing the workload associated with patient repositioning, allowing caregivers to focus on other critical aspects of patient care.

Limitation

The study has several limitations that should be considered when interpreting the findings. First, the quasi-experimental design employed limits the ability to establish a causal relationship between the intervention and outcomes, as there is no randomisation to account for potential confounding factors. Additionally, the use of convenience sampling may introduce selection bias, as the sample may not be representative of the broader population of stroke patients. The relatively small sample size, calculated at 15 participants per group, reduces the generalisability of the results and increases the risk of type II error. Furthermore, the study was conducted in a single private hospital in West Java, which may limit the applicability of the findings to other settings or regions. Another limitation lies in the intervention period of only one month, which may not adequately capture the long-term effects of the smart bed on pressure ulcer risk reduction. The reliance on the Braden scale, although widely used, may not comprehensively evaluate all factors influencing pressure ulcer development. Additionally, the exclusion of patients with cognitive or mental disorders and those with significant limitations in the range of motion might limit the study's applicability to more diverse patient populations.

CONCLUSION

The findings of this study indicate that the implementation of a smart bed significantly enhances patient care, particularly in reducing the risk of pressure ulcers. The bed's ability to autonomously rotate patients, regulate humidity levels, and minimise friction contributes to improved patient outcomes. When compared to existing smart bed solutions, the proposed bed offers a more advanced, user-friendly, and low-maintenance alternative, aligning with the latest advancements in automated healthcare solutions. Future research should focus on large-scale clinical trials to further evaluate the long-term efficacy and patient satisfaction associated with smart bed utilisation.

Further research is needed to evaluate the long-term effectiveness and cost-efficiency of the smart bed system in diverse clinical settings and home environments. Expanding the system's capabilities, such as incorporating advanced AI algorithms for predictive analytics and integrating remote healthcare monitoring features, could significantly enhance patient outcomes. Additionally, conducting larger scale randomised controlled trials across different patient populations would provide robust evidence for its clinical applicability. The smart bed's design could also be adapted to address other healthcare needs, such as rehabilitation support or chronic disease management, broadening its utility and impact in the medical field.

Conflict of Interest

The authors declare that they have no competing interests.

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