RESEARCH PAPER

The Impact of Smart Bedside Technology on Nursing Compliance with Infection Control Bundles in Intensive Care Units

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Abstract

Background: Infection control in Intensive Care Units (ICUs) is a critical priority to reduce healthcare-associated infections. Despite established protocols, nursing compliance often faces challenges related to workload and monitoring accuracy. Smart bedside technology offers an innovative solution to enhance adherence through automated reminders and real-time data tracking. This study aimed to evaluate the impact of Smart Bedside Technology on nursing compliance with infection control bundles among nurses working in the in Intensive Care Units. **Subjects and Method:** A quasi-experimental (pre-test/post-test) design was conducted on a convenience sample of 50 nurses working in the Intensive Care Units at Sohag University Hospitals. Data was assessed using: **Tool I:** Nurses' demographic and professional profile, Tool II: Observational checklist for infection control compliance Tool III: Nurses' perception of smart bedside technology scale, and Tool IV: Automated Digital Audit Log (Technology Data). **Results:** The study findings revealed a significant improvement in overall compliance rates after the intervention. Hand hygiene adherence increased Post-intervention ($P<0.001$). Furthermore, compliance with device-related infection protocols showed a statistically significant elevation. Nurses reported that real-time visual and auditory prompts from the smart bedside technology were the primary factors in reducing protocol omissions. **Conclusion:** Implementing smart bedside technology in the ICUs of Sohag University Hospitals effectively boosted nursing compliance with infection control measures. The study recommends integrating these technologies as a standard part of ICU infrastructure to ensure patient safety and support nursing performance.

Keywords: Infection Control, Intensive care units, Nursing Compliance, Smart Bedside Technology.

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Introduction

Healthcare-associated infections (HAIs) represent a significant global public health challenge, particularly within Intensive Care Units (ICUs). Patients in the ICU are uniquely vulnerable due to their critical clinical status, compromised immune systems, and the frequent use of invasive medical devices such as central venous catheters and mechanical ventilators. Studies indicate that the prevalence of HAIs in ICUs is significantly higher than in general wards, leading to prolonged hospital stays, increased healthcare costs, and elevated mortality rates **(Vincent et al., 2020).**

Nurses are the primary caregivers in the ICU and play a pivotal role in preventing the transmission of pathogens. Compliance with infection control protocols—specifically hand hygiene, the use of Personal Protective Equipment (PPE), and device-related bundles is the most effective strategy for reducing HAIs. In Egypt, and specifically in high-volume tertiary centers, the burden of HAIs remains a priority. Managing these infections requires rigorous adherence to standardized protocols, yet the complexity of the ICU environment often makes consistent compliance difficult to maintain **(World Health Organization [WHO], 2009).**

Despite the existence of evidence-based guidelines, actual compliance rates among nursing staff often fall below recommended levels. Research suggests that "behavioral drift" and "omission errors" occur due to high nurse-to-patient ratios, emergency situations, and "alarm fatigue". Manual monitoring of compliance is also prone to the "Hawthorne Effect," where nurses temporarily improve their behavior only when they know they are being observed, leading to inaccurate data **(Srigley et al., 2014).**

To address the limitations of human observation and manual reminders, the healthcare sector is increasingly turning to Smart Bedside Technology. This involves the integration of the Internet of Things (IoT), wearable sensors, and automated monitoring systems directly into the patient's bedside environment**.** Smart beds can now be equipped with sensors that track the presence of healthcare providers, detect hand hygiene dispenser usage, and provide real-time visual or auditory prompts if a protocol step is missed. This technology moves beyond passive surveillance to active intervention, providing immediate feedback that reinforces correct behavior at the point of care **(Haque et al., 2020)**.

As part of the digital transformation strategy in Egyptian university hospitals, there is a growing interest in adopting health informatics to improve nursing performance. It serve a vast population in UpperEgypt , where the ICU environment is characterized by high turnover and critical cases. Introducing smart bedside technology in such settings provides a dual benefit: it supports nurses by reducing cognitive load and ensures a higher safety margin for patients through continuous, automated monitoring (**Zhang et al., 2023**).

based -The "Bundle" approach is an evidence clinical strategy designed to improve patient outcomes by grouping a small set of interventions (typically 3 to 5) that, when ficantly performed together, result in signi better outcomes than when implemented individually. In the ICU, two primary bundles are of utmost importance. -Ventilator Associated Pneumonia (VAP) Bundle: VAP is a leading cause of morbidity in the ICU **(Humbre & Shah, (2025)**The standard . :includes bundle Elevation of the Head of the :Bed (HOB) Maintaining an angle between 30° and 45°. Daily "Sedation :"Vacations Assessing readiness to wean from .the ventilator Peptic Ulcer Disease (PUD) .Prophylaxis Deep Vein Thrombosis (DVT) .Prophylaxis .are with ChlorhexidineOral C Associated Bloodstream -Central Line Infection (CLABSI) Bundle: This bundle focuses on strict aseptic techniques during insertion and daily maintenance of central venous catheters, including site inspection and y catheter manipulationhand hygiene before an **(Ahmed et al., 2025).**

The core innovation of this study lies in how Smart Bedside Technology transforms these passive protocols into Active Clinical Reminders. While traditional bundles rely on the nurse’s memory and manual tation, the smart system providesdocumen; :Automated HOB Monitoring Smart beds are equipped with digital inclinometers. If the bed angle drops below 30°for a patient on a ventilator, the system triggers a Visual Alert on the bedside monitor or a Vibrating Alert on the nurse’ handheld device s**(Humbre ,Shah & 2025)**

Using IoT (Internet of Things) sensors, the bed detects when a nurse enters the "Patient Zone." If the nurse approaches the patient without first based hand rub -activating the alcohol is linked to the bed's system), dispenser (which Auditory Prompt an is issued immediately**.** For patients under isolation precautions (e.g., MDROs), the smart bed system can be programmed to display a digital "Isolation Shield" icon. It monitors whether the nurse has with the PPE station before bedside engaged -interaction, reducing the risk of cross contamination **Haque et al., 2020))**.

One of the primary barriers to compliance in Sohag University Hospitals' ICUs is Cognitive Overload." Nurses often manage " patients simultaneously. acuity-multiple high Smart technology acts as a "Digital Assistant" that reduces the mental effort required to track every step of the infection control protocol. By providing Time Data Tracking, it -Real eliminates the need for retrospective manual diting, allowing nurses to focus more on au direct patient care while ensuring that no **Boyce)** critical safety step is omitted**, 2017).**

Implementing advanced IoT-based solutions in regional academic centers, presents unique infrastructural and logistical challenges. A primary technical barrier is the Stability of Wireless Connectivity (Wi-Fi); smart bedside systems require a seamless and robust network to ensure that real-time alerts and data logs are transmitted without latency. Furthermore, the Interoperability between new smart hardware and existing legacy hospital systems can be complex. Another significant challenge is the Need for Continuous Technical Training. In the context of Upper Egypt, where nursing turnover can be high and digital literacy levels vary, establishing a sustainable "Tech-Support" culture is essential. This includes not only initial training but also ongoing maintenance to prevent "System Distrust" that occurs when sensors malfunction or provide false-positive alarms**.** Addressing these local challenges is crucial for the long-term success and scalability of smart technology in the ICU **(Haque et al., 2020)**.

Significance of the Study

The significance of this study lies in its focus on the intersection of nursing practice and technological innovation. While many studies have looked at infection control in general, fewer have evaluated how specific "smart" bedside interventions impact nursing behavior in the Egyptian context. By using a quasi-experimental design (pre/post-test) with a sample of nurses, this study provides empirical evidence on whether automated reminders can bridge the gap between protocol knowledge and clinical practice. The findings from this research are expected to provide a blueprint for hospital administrators at Sohag University to integrate smart technologies into ICU infrastructure, ultimately improving patient outcomes and nursing professional standards **(Humbre & Shah, 2025).**

The introduction of smart bedside technology often raises concerns regarding "Workplace Surveillance" and its impact on nursing autonomy. However, the ethical framework of this study emphasizes that Smart Monitoring is not a tool for punitive supervision but a Supportive Safety Mechanism. Ethically, the primary goal is the "Principle of Beneficence"—acting in the best interest of the patient to prevent life-threatening infections (**Beauchamp & Childress, 2019).** For the nursing staff, this technology serves as a "Digital Safety Net" that protects them from unintentional omissions caused by fatigue or high cognitive load. By providing real-time prompts, the system ensures that the nurse's professional accountability is supported by objective data, shifting the focus from "watching the nurse" to "safeguarding the care process." This approach fosters a Culture of Safety rather than a culture of blame, ensuring that both the provider and the recipient of care are protected within a transparent clinical environment.

Study Aim:
The aim of this study was to evaluate the impact of Smart Bedside Technology on nursing compliance with infection control bundles in the Intensive Care Units through:

1. Assess the baseline (pre-intervention) compliance levels of ICU nurses regarding infection control protocols (Hand hygiene, PPE, and Device bundles).
2. Implement smart bedside technology as an intervention to provide real-time monitoring and feedback.
3. Compare nursing compliance rates before and after the implementation of the smart bedside system.
4. Explore nurses' perceptions and acceptance of using smart technology in their daily clinical workflow.

Research Hypotheses:
Hypothesis 1 : There will be a statistically significant improvement in the mean compliance scores of ICU nurses regarding hand hygiene protocols after the implementation of smart bedside technology compared to their pre-intervention scores.

Hypothesis 2 : Nursing adherence to Personal Protective Equipment (PPE) and device-related infection bundles (VAP/CLABSI) will be significantly higher in the post-intervention phase than in the pre-intervention phase.

Hypothesis 3 : There will be a positive correlation between the frequency of real-time technological alerts (auditory/visual prompts) and the rate of immediate corrective actions taken by the nurses.

Subjects and Method:

Research Design

A quasi-experimental research design (one-group pre-test/post-test design) was employed to achieve the study's objectives. This design is suitable for evaluating the effectiveness of a technological intervention on nursing performance within a clinical setting.

Research Setting
The study was conducted in the Intensive Care Units (ICUs) at Sohag University Hospitals, Egypt. This setting was selected due to its high patient acuity, the complexity of nursing care, and the critical need for strict infection control compliance.

Subjects
A convenience sample of 50 nurses working in the aforementioned ICUs was included in the study.

- **Inclusion Criteria:** Nurses of both genders, regardless of their educational level, with at least six months of experience in the ICU, and who were willing to participate in the study.
- **Exclusion Criteria:** Nurses on long-term leave or those who did not complete both the pre- and post-intervention phases.

Data Collection Tools
Data were collected using four distinct tools:
Tool I: Nurses' Demographic and Professional Profile: Developed by the researcher to collect data on age, gender, education, and ICU experience.It included general demographic characteristics such as age, gender, educational level, years of experience in ICU, previous training on infection control protocols, and previous exposure to smart medical technology.

Tool II: Observational Checklist for Infection Control Compliance: Used to monitor hand hygiene, PPE usage, and device-related bundles (VAP/CLABSI). it was adopted from **(World Health Organization (WHO). (2009).**

1. **It included Hand Hygiene Adherence:** Following the WHO "5 Moments" (before/after patient contact).
2. **PPE Compliance:** Correct donning/doffing of gloves, masks, and gowns.

3. **Bundle Care Compliance:** Implementation of VAP (Ventilator-Associated Pneumonia) and CLABSI (Central Line-Associated Bloodstream Infection) protocols.
4. **Environmental Cleaning:** Disinfecting high-touch bedside surfaces.

- **Measurement Levels :** Binary scale (**Compliant / Non-Compliant**).

Tool III: Nurses' Perception of Smart Bedside Technology Scale: A 5-point Likert scale (based on the Technology Acceptance Model) to assess the nurses' attitudes toward the intervention. It was adopted from **Davis, (1989) . It included**

1. **Perceived Usefulness:** Does the technology help in remembering protocols?
2. **Perceived Ease of Use:** Is the smart interface user-friendly?
3. **Impact on Workflow:** Does it reduce the time spent on manual documentation?
4. **Alarm Fatigue:** Are the alerts helpful or distracting?

- **Measurement Levels :** 5-point **Likert Scale** (1 = Strongly Disagree to 5 = Strongly Agree).

Tool IV: Automated Digital Audit Log: An electronic system integrated into the smart bedside technology to record real-time compliance data and alert triggers. It was adopted from **Haque et al. (2020)**

- **It included:**

1. **Alert Trigger Frequency:** How many times did the bed alert for a breach in protocol?
2. **Correction Time:** The duration between the alert and the nurse's corrective action.
3. **Sensor Accuracy:** Comparison between automated logs and manual observation.

- **Measurement Levels: Ratio Scale** (Numerical counts and time in seconds/minutes).

Validity:

To ensure the face and content validity of the study tools (Tool I, II, and III), they were submitted to a panel of five experts in the fields of Medical-Surgical Nursing and Infection Control from the Faculty of Nursing. The experts reviewed the tools for:

- **Clarity:** The ease of understanding the items.
- **Relevance:** The extent to which the items measure nursing compliance and smart technology impact.
- **Comprehensiveness:** Whether all aspects of ICU infection control protocols were covered. Based on their feedback, no adjustments were made.

Reliability

The reliability of the structured tools was tested using Cronbach's Alpha coefficient to measure internal consistency. A Cronbach's alpha of 0.85, indicating that the tool is highly reliable.

Pilot Study:

A pilot study was conducted on 10% of the sample (5 nurses) from the ICUs at Sohag University Hospitals. To test the feasibility and applicability of the smart bedside technology in a real clinical setting. To estimate the time required for completing the checklists and questionnaires. To identify any technical issues with the sensors or the wireless connectivity in the ICU.

Ethical Considerations:

Official permission was obtained from the Ethical Committee (No: 135/ 3-11-2023) of the Faculty of Nursing and the administrators of Sohag University Hospitals. Written informed consent was obtained from each of the 50 nurses after explaining the study's aim, benefits, and the nature of the technological intervention. Participants were assured that their data would remain anonymous (using coding instead of names) and would be used solely for research purposes, not for administrative performance evaluations. Nurses were informed of their voluntary participation and their right to withdraw from the study at any time without any negative consequences on their job status.

Data Collection Procedure

The data collection process was conducted over a period of **six months** (from November 2023 to April 2023). The procedure followed a systematic four-phase approach:

Phase I: Assessment Phase (Pre-intervention)

- **Baseline Observation:** The researcher used **Tool II (Observational Checklist)** to monitor the 50 nurses during their routine shifts. Each nurse was observed for at least three different clinical interactions (e.g., wound dressing, suctioning, or catheter care).

- **Hidden Observation:** To minimize the **Hawthorne Effect** (behavior change due to being watched), observations were conducted discreetly by trained clinical observers.

- **Initial Survey:** Nurses completed **Tool I (Demographic Profile)** to establish their background and experience levels.

Phase II: Preparatory & Planning Phase

- **Equipment Setup:** The Smart Bedside Technology (including IoT hand-hygiene sensors, bed-angle inclinometers for VAP prevention, and bedside visual/auditory alert monitors) was installed in the selected ICU cubicles at Sohag University Hospitals.

- **Educational Workshop:** A 3-day training program was organized for the 50 nurses. The training covered:

1. The technical operation of the smart bedside system.
2. How to respond to real-time auditory and visual alerts.
3. The scientific rationale behind the infection control bundles (VAP & CLABSI).

Phase III: Implementation Phase (The Intervention)

- **Active Monitoring:** The smart system was activated for a duration of **8 to 12 weeks**.

- **Real-time Feedback:** Whenever a nurse approached the "Patient Zone" without disinfecting their hands or if the bed angle was incorrect for a ventilated patient, the system triggered an immediate alert (e.g., a yellow flashing light or a soft beep).

- **Automated Logging:** Tool IV (Digital Audit Log) automatically recorded every protocol breach and the subsequent corrective action taken by the nurse in real-time.

Phase IV: Evaluation Phase (Post-intervention)

- **Final Observation:** The researcher repeated the direct observation using Tool II to measure the change in compliance behavior after the nurses became accustomed to the technology.

- **Perception Assessment:** Nurses were asked to complete Tool III (Perception Scale) to evaluate their satisfaction, the system's ease of use, and any challenges like "alarm fatigue."

- **Data Integration:** Electronic logs from the smart beds were compared with the manual observation checklists to ensure data triangulation and accuracy.

Statistical analysis:

Data were analyzed using SPSS (Version 26.0), where descriptive statistics, including frequencies, percentages, means, and standard deviations, were used to summarize the nurses' demographic profiles and perception levels. To test the research hypotheses, a Paired t-test was employed to compare the mean compliance scores of the 50 nurses before and after the intervention, while Pearson's Correlation Coefficient was used to examine the relationship between technological alert frequency and adherence rates. The internal consistency of the tools was verified using Cronbach's Alpha, and all statistical tests were conducted at a significance level of $P < 0.05$, ensuring the reliability of the findings within the ICU context of Sohag University Hospitals.

Results:

Table 1: Demographic and Professional Profile of the Studied Nurses (N=50)

Demographic Characteristics	Frequency (n)	Percentage (%)
Age (Years)		
21 – 30	31	62.0
31 – 40	14	28.0
> 40	5	10.0

Gender		
Male	12	24.0
Female	38	76.0
Educational Qualification		
Technical Nursing Diploma	18	36.0
Bachelor of Nursing (B.Sc.N)	27	54.0
Postgraduate Studies	5	10.0
Years of ICU Experience		
< 5 years	26	52.0
5 – 10 years	16	32.0
> 10 years	8	16.0

Table 1: The results indicate that more than half of the studied nurses (**62.0%**) were in the young age group (21–30 years), and the majority (**76.0%**) were females. Regarding education, **54.0%** held a Bachelor's degree in Nursing. Additionally, **52.0%** of the sample had less than five years of experience in the ICU.

Table 2: Comparison of Nursing Compliance with Infection Control Protocols Pre and Post-Intervention (N=50)

Infection Control Domains	Pre-Intervention (Mean ± SD)	Post-Intervention (Mean ± SD)	t-test	p-value
Hand Hygiene Compliance	11.2 ± 3.4	18.5 ± 1.2	14.52	**< 0.001***
PPE Usage Adherence	13.8 ± 2.9	19.2 ± 0.8	12.18	**< 0.001***
Device-Related Bundles (VAP/CLABSI)	10.4 ± 3.6	17.8 ± 1.5	13.44	**< 0.001***
Environmental Surface Safety	12.1 ± 2.5	18.1 ± 1.1	11.25	**< 0.001***
Total Compliance Score	**47.5 ± 12.4**	**73.6 ± 4.6**	**15.82**	**< 0.001***

Table 2: This table demonstrates a highly statistically significant improvement in all domains of infection control compliance following the implementation of smart bedside technology. The total compliance score increased from a baseline mean of 47.5 to 73.6 post-intervention.

Table 3: Nurses' Perception of Smart Bedside Technology Scale (N=50)

Perception Items (Likert Scale)	Mean Score	SD	Level of Acceptance
1. Usefulness in preventing errors	4.72	0.41	High
2. Ease of interacting with the system	4.45	0.58	High
3. Reliability of real-time alerts	4.61	0.49	High
4. Impact on reducing cognitive workload	4.38	0.62	High
Overall Perception Score	**4.54**	**0.52**	**High**

Table 3: The data shows that ICU nurses at Sohag University Hospitals have a high level of positive perception toward smart bedside technology, with an overall mean score of 4.54/5. The highest scores were related to the technology's "Usefulness in preventing errors" (4.72).

Table 4: Analysis of Automated Digital Audit Logs and System Accuracy (N=50)

Technology Metrics (Ratio Scale)	Mean Value	Range / SD
Alert Trigger Frequency (Alerts per shift)	14.5	8 – 22
Correction Time (Seconds)	12.4 sec	± 4.2 sec
Sensor Accuracy (Compared to manual)	96.8%	± 1.5%

Table 4: Reveals a high system Accuracy of 96.8%, validating the reliability of the smart sensors. The Correction Time averaged 12.4 seconds.

Table 5: Correlation Between Technological Alert Frequency and Nursing Compliance (N=50)

Variables	Pearson Correlation (r)	p-value
Total Alert Frequency vs. Compliance Score	0.842	**< 0.001***
Alert Correction Time vs. Experience Years	-0.615	**< 0.01***

In Table 5: A strong positive correlation (0.842) was found between the frequency of smart alerts and nursing compliance, suggesting that the more the system prompts the nurse, the higher the adherence to the protocol. Furthermore, a negative correlation (-0.615) was observed between years of experience and alert correction time, meaning that more experienced nurses responded faster to the system's alerts.

Discussion:

The results of the current study indicated that more than half of the studied nurses were in the young age group (21–30 years), and the majority were females, held a Bachelor's degree in Nursing, and had less than five years of experience in the ICU, suggesting a relatively young workforce at Sohag University Hospitals who are likely to be more receptive to technological interventions and generation of nurses who are likely "digital natives."

These findings are consistent with **Silang et al. (2026)** and **Saad et al., (2025)**, who observed a similar trend in Egyptian university hospitals where the majority of ICU nursing staff are recent graduates. This demographic shift is often attributed to the high turnover or migration of senior nurses, leaving ICUs staffed by younger, more technologically receptive clinicians. Furthermore, the high percentage of Bachelor's degree holders aligns with **Dailah et al. (2024)**, who noted that higher educational attainment in nursing is increasingly linked to better integration of smart technologies and adherence to complex clinical protocols.

The results differ from studies conducted in Western healthcare systems, such as **Adhikari & Smith, (2023)**, where the nursing workforce in critical care tends to be older (mean age >40) with more extensive years of experience. While a literature **Rahajeng & Muslimah, (2019)** argues that a lack of experience (less than 5 years) might hinder clinical judgment in ICUs, the high receptivity to technological interventions found in this study suggests that youthful adaptability may compensate for shorter clinical tenure when using smart alert systems.

The implementation of smart bedside technology led to a remarkable and statistically significant increase in total compliance scores, rising from 47.5 to 73.6. This finding underscores the transformative role of real-time digital prompts in clinical environments. This confirms that real-time automated reminders effectively bridged the gap between theoretical protocols and clinical practice.

These results are consistent with the findings of **Zhang et al. (2023)**, whose meta-analysis demonstrated that intelligent hand hygiene technologies significantly improve healthcare workers' compliance and reduce healthcare-associated infection (HAI) rates. Similarly, **Hugo et al. (2022)** reported that digital rounding tools and real-time feedback iteratively increased maintenance bundle compliance, highlighting how automated reminders bridge the "theory-practice gap". The success of this intervention also aligns with the SMART principle management methods discussed by **Zhang et al. (2023)**, which emphasize that specific, measurable, and time-bound goals effectively enhance staff awareness and adherence to preventive protocols.

While the current study shows a clear upward trend, some systematic reviews, such as **Thandar et al. (2022)**, caution that while specialized teams and link-nurse systems improve compliance, they do not always lead to a statistically significant reduction in actual infection incidence rates due to factors like high risk of bias or workload burdens. Furthermore, **Madran et al. (2025)** found that despite high awareness, full compliance is rarely achieved in practice due to meso-level barriers such as unexpected medical emergencies and excessive workloads, which can sometimes overshadow the benefits of technological reminders.

The study identifies a high level of positive perception among ICU nurses toward smart bedside technology. This enthusiastic reception is anchored in the technology's perceived "Usefulness in preventing errors", which received the highest score (4.72), indicating that nurses value the "safety net" provided by automated monitoring in high-pressure environments.

This favorable attitude aligns with the Technology Acceptance Model (TAM**)**, which posits that "Perceived Usefulness" is the primary determinant of a user's intention to adopt a new system. These results mirror findings by **Kutney-Lee et al. (2019)**, who noted that nurses in high-acuity settings (like the ICU) readily embrace technologies that act as a "Safety Net", reducing the cognitive load associated with complex monitoring. Furthermore, **Roberts et al. (2016)**, found that when nurses perceive technology as a tool for error prevention, their satisfaction levels and professional confidence increase significantly. The high score for error prevention also supports the findings of **Zhang et al. (2023)**, who emphasized that real-time automated monitoring is valued by clinicians specifically for its ability to provide an "extra layer of safety" in high-pressure environments.

These results contrast with studies highlighting "Technophobia" or resistance among nursing staff. For instance, **Adhikari & Smith, (2023)**, reported that in some older workforce cohorts, technology is often viewed as a "barrier" to direct patient care or a source of increased documentation burden. However, the high mean score (4.54) in the current study suggests that the nurses at Sohag University Hospitals have moved beyond these traditional barriers, likely due to their young age and academic preparation, viewing technology as an enhancer rather than a hindrance.

The automated data highlighted the technical robustess of the smart bedside technology, with a reported a high system accuracy. This high level of reliability is fundamental to gaining the trust of nursing staff and ensuring the clinical validity of the intervention which explains the high compliance rates observed in Tool II.

The high accuracy rate aligns with findings by **Zhang et al. (2023)**, who noted that advanced sensor-based monitoring systems must exceed accuracy to effectively minimize false positives and maintain clinician engagement. This reliability directly addresses the root cause of "distrust in alarm systems," as discussed in recent reviews of **Intelligent Alarm Management**. Furthermore, the rapid **Correction Time (12.4 seconds)** is consistent with the results of **Ma et al. (2025)** and **Yu et al. (2021)**, who demonstrated that visual and auditory multi-sensory prompts significantly reduce response times compared to traditional auditory-only alarms. This immediate intervention explains the substantial improvements in infection control compliance observed in earlier phases of the study, as it ensures that protocols are followed precisely at the "point of care".

These results stand in stark contrast to traditional ICU environments where, according to **Lewandowska et al. (2020)**, up to half of alarms are multi-parameter monitor alerts that are often ignored or answered with significant delays due to poor specificity. While standard literature suggests that a high frequency of alerts typically leads to delayed responses, the 12.4-second average in this study indicates that the "smart" nature of these prompts—being both accurate and actionable—effectively bypassed the typical behavioral lag associated with alarm-ridden environments.

The strong positive correlation between alert frequency and protocol compliance indicated that digital prompting serves as a critical driver for clinical adherence and meaning that more experienced nurses responded faster to the system's alerts. This finding aligns with the Technology Acceptance Model (TAM) and studies by **Tollinche et al. (2020)**, which argue that Clinical Decision Support Systems (CDSS) reduce reliance on human memory, thereby minimizing omissions in fast-paced environments. The high correlation suggests that the alerts were perceived as useful rather than intrusive. In a literature on "Alert Fatigue" **by Gülşen et al., (2025)** suggests that increased frequency often leads to "desensitization," where nurses begin to ignore prompts. However, the results in Table 5 contradict this trend, suggesting that the alerts in this specific system were likely high-quality, relevant, and actionable, preventing the typical decline in compliance associated with high-frequency notifications.

Limitations:

- The study was limited to a convenience sample of 50 nurses in a single geographical location, which may limit the generalizability of the findings to all Egyptian hospitals.
- Despite efforts to conduct hidden observations, the presence of the technology itself might have temporarily influenced nursing behavior (Observation Bias) during the initial phases.

Conclusion

The study concluded that Smart Bedside Technology has a transformative impact on nursing performance in intensive care settings. Implementing automated, real-time feedback systems led to a statistically significant improvement in nursing compliance with infection control protocols, particularly in hand hygiene and device-related bundle care. The technology serves as a "digital safety net" that reduces human error and cognitive overload. Furthermore, the high level of acceptance among the 50 studied nurses indicates that such innovations are not only effective but also well-received as supportive tools in high-pressure clinical environments.

Recommendations:

Based on the study findings, the following are recommended:

- **Institutional Integration:** Hospitals should consider integrating smart bedside technology as a standard component of ICU infrastructure to ensure continuous monitoring of infection control.
- Developing specialized training programs for ICU nurses on the use of health informatics and smart sensors to maintain high levels of digital literacy.
- Periodic auditing and calibration of smart sensors are necessary to minimize alarm fatigue and ensure data accuracy.
- Nursing administrations should update standard operating procedures (SOPs) to include automated digital logs as a primary tool for quality auditing and performance feedback.

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