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Nursing-Led Monitoring and Intervention in the Tech-Enabled ED: A Narrative Review of Competencies for Advanced Medical Devices

Miad Ahmed AJbarah [(1)], Amal Ali Makki Hanshli [(2)], Reham Hussain Hamami [(2)], Jawaher Ali Makey Hanshali [(3)], Abbas Mohammed Ali Hakami [(4)], Salem Ali Alolayan [(5)], Manal Aiydh Alharthi [(6)], Seef Madallah A Alshrari [(7)], Kaseb Ayed Musallam Alsharari [(8)], Salha Abdullah Bahkeem [(9)], Fawzia Fawaz Hamdi Al-Haiti [(10)], Dohaya Fawaz Hamdi Alhayti [(11)]

(1) North Jubail Health Center / Jubail,Ministry Of Health, Saudi Arabia,
(2) Prince Mohamed bin Nasser Hospital,Ministry Of Health, Saudi Arabia,
(3) Qaim aldash PHC,Ministry Of Health, Saudi Arabia,
(4) Jazan Health Cluster - Ambulance Transport,Ministry Of Health, Saudi Arabia,
(5) King Salman Hospital - First Health Cluster, Ministry Of Health, Saudi Arabia,
(6) Hafr Al-Batin Health Cluster - Al-Qaisumah Hospital, manal,Ministry Of Health, Saudi Arabia,
(7) Al-Qurayyat General Hospital, Al-Qurayyat, Al-Jawf Health Cluster,Ministry Of Health, Saudi Arabia,
(8) Al-Arizi Health Center, Al-Qurayyat, Al-Jawf Health Cluster,Ministry Of Health, Saudi Arabia,
(9) Ministry Of Health, Saudi Arabia,
(10) Al-Iskan Charitable Health Center, Hail Health Cluster, Ministry Of Health, Saudi Arabia,
(11) Alhayt General Hospital, Hail Health Cluster, Ministry Of Health, Saudi Arabia

Abstract

Background: The integration of advanced medical devices in emergency care has created a complex human-tech interface, with nurses as primary operators. Device competency is vital for patient safety, but challenges like alarm fatigue, usability issues in crises, and the need for quick data interpretation highlight a gap between technology and clinical application.

Aim: This narrative review aims to synthesize current evidence on the competencies required by emergency nursing staff to safely and effectively operate advanced medical devices, examining the interplay between nursing practice, emergency medicine workflows, and device design.

Methods: A comprehensive literature search was conducted across PubMed, CINAHL, Scopus, and IEEE Xplore databases for peer-reviewed articles published between 2010-2024.

Results: The review identifies five core competency domains: technical-procedural (operation), analytical-interpretive (data synthesis), situational (crisis usability), interprofessional (communication), and adaptive (troubleshooting). Effective high-fidelity simulation and just-in-time training models show promise in improving competency. Persistent issues include pervasive alarm fatigue, often exacerbated by poor device design, and a frequent disconnect between device data and interdisciplinary clinical decision-making.

Conclusion: Nursing-led device management in the ED is a linchpin of patient safety. Competency must be reconceptualized beyond basic operation to encompass data interpretation and human factors. A tripartite alignment of robust, continuous nursing education, purposeful interprofessional collaboration, and human-centered device design is essential to mitigate risk and optimize outcomes in tech-enabled emergency care.

Keywords: Emergency Nursing, Clinical Competence, Medical Devices, Patient Safety, Human Factors Engineering.

Introduction

The modern Emergency Department (ED) is a technologically dense ecosystem where patient outcomes hinge on the seamless interaction between clinicians and advanced medical devices (Park et al., 2023). Nurses, as the constant caregivers at the bedside, are primarily responsible for the operation, monitoring, and initial troubleshooting of a vast array of technology, including but not limited to ventilators, smart infusion pumps, non-invasive and invasive hemodynamic monitors, and capnography units (Al-Ghabeesh & Qattom, 2018). This nursing-led monitoring and intervention represents a critical juncture in patient safety. However, the ED environment—characterized by noise, interruptions, time pressure, and high acuity—creates a uniquely challenging context for the human-tech interface (Friedman et al., 2017).

Competency, therefore, cannot be defined merely by the ability to turn on a device; it must encompass the synthesis of data under stress, the management of cascading alarms, and the effective communication of device-derived insights to the broader team (Bagherian et al., 2017). This narrative review synthesizes literature from 2010 to 2024 to explore the competencies required for advanced

*Corresponding author e-mail: maljbarah@moh.gov.sa (Miad Ahmed AJbarah).

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medical device management in the ED, examining the triad of nursing practice, emergency medicine workflows, and medical device design. It argues for an integrated model where competency development, interprofessional collaboration, and human-centered design are imperative to safeguard patient safety.

The Competency Imperative: Beyond Basic Operation

Nursing competency with medical devices has traditionally been framed in procedural terms. Yet evidence suggests that this is insufficient. True competency is a multifaceted construct. Technical-Procedural Competency remains foundational; errors in programming infusion pumps, for instance, are a well-documented source of adverse drug events (Husch et al., 2005). However, Analytical-Interpretive Competency is increasingly vital. A nurse must not only see a waveform on a hemodynamic monitor but must interpret its meaning in the context of the patient's overall condition, distinguishing between artifact and clinical deterioration (Driscoll et al., 2023; Pang et al., 2017). This is closely tied to Situational Competency, which involves managing devices during crises like resuscitation or rapid sequence intubation, where device usability is tested (Trygg Lycke et al., 2023).

Furthermore, Interprofessional Competency is crucial. The nurse's role in interpreting and communicating device data (e.g., trending capnography values or cardiac output indices) directly informs medical decision-making by physicians and advanced practice providers (Baker, 2016). Failure in this communication chain can lead to diagnostic or treatment delays. Finally, Adaptive Competency—the ability to troubleshoot basic device failures, manage defaults, and switch to backup modes—is essential for maintaining care continuity during technical interruptions (García-Martín et al., 2021). The pressure of the ED amplifies the need for all these competencies to be honed to an instinctive level, a requirement that static, one-time training rarely meets. These domains are summarized in Table 1 & Figure 1.

Table 1: Core Competency Domains for Nursing-Led Advanced Device Management in the ED

Domain	Definition	Example in ED Practice
Technical-Procedural	Ability to correctly set up, operate, and perform basic maintenance on a device.	Programming a triple-channel infusion pump for vasoactive drugs; initiating ventilator settings for a newly intubated patient.
Analytical-Interpretive	Ability to interpret device-generated data and waveforms in the clinical context.	Distinguishing true arrhythmia from motion artifact on the cardiac monitor; interpreting trending capnography waveform morphology during CPR.
Situational	Ability to manage devices effectively during high-stakes, time-sensitive crisis situations.	Adjusting ventilator settings during a patient's sudden deterioration; rapidly switching monitor leads during a resuscitation while maintaining data flow.
Interprofessional	Ability to communicate device data and concerns effectively to the physician/team to inform decision-making.	Articulating a concerning trend in intracranial pressure readings; advocating for a medication change based on poor response seen on hemodynamic monitoring.
Adaptive	Ability to troubleshoot common device problems and implement contingency plans.	Responding to a "occlusion" alarm by systematically checking the IV line; switching to a backup transport monitor when the primary device fails.

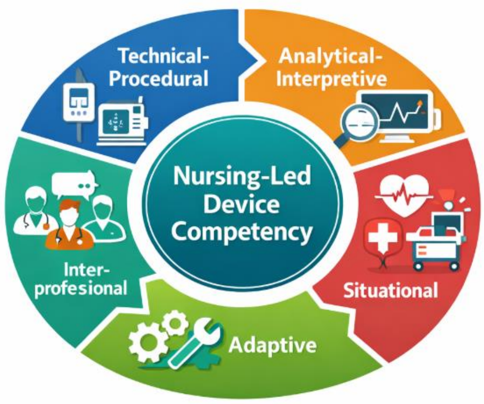

Figure 1. Core Competency Domains for Nursing-Led Advanced Medical Device Management

The Burden of Bad Design: Alarm Fatigue and Usability Crises

A central theme in the literature is that nursing competency is profoundly mediated by the design of the devices themselves. Alarm fatigue, defined as desensitization due to excessive, non-actionable alarms, is a pervasive and dangerous phenomenon (Sendelbach & Funk, 2013). Studies consistently show that over 85% of alarms in critical care settings require no intervention, leading nurses to intuitively, and sometimes dangerously, adjust thresholds, disable alarms, or delay responses (Winters et al., 2018). This is not solely a nursing behavior problem but a direct consequence of poor device design that prioritizes sensitivity over specificity (Oliveira et al., 2018). In the ED, with its high patient turnover and lack of established baselines, this problem is exacerbated.

Usability under pressure is another critical design failure. Interfaces that are intuitive in a quiet lab may become inscrutable during a "code blue" (Carayon et al., 2020). Small touchscreen buttons, complex menu hierarchies, and a lack of standardized controls across different manufacturers increase cognitive load and the risk of error (Jackson et al., 2019). Human Factors Engineering (HFE) principles, which involve designing systems to match human capabilities and limitations, are frequently overlooked in medical device development (Proctor & Van Zandt, 2018). When devices lack fail-safe modes, clear status indicators, or intuitive troubleshooting guides, they place an unreasonable burden on the nurse's adaptive competency, transforming technical glitches into potential safety events (Carayon et al., 2021; Keebler et al., 2022). Figure 2 illustrates the key challenges at the human–technology interface in the emergency department—including alarm fatigue, poor usability under crisis conditions, and data interpretation gaps—and corresponding mitigation strategies such as human-centered design, simulation-based training, just-in-time education, and interprofessional communication pathways.

Training Models: Bridging the Competency Gap

Given the challenges, effective training models are paramount. The literature moves decisively away from passive, lecture-based in-services towards active, contextual learning. High-fidelity simulation emerges as a gold standard, allowing nurses to practice the integration of technical, analytical, and situational competencies in a risk-free environment (Foronda et al., 2020). Scenarios simulating ventilator dyssynchrony, pump programming errors, or monitor misinterpretation can build critical thinking and muscle memory (Gilfoyle et al., 2017). Just-in-Time (JIT) and point-of-care training, delivered via mobile resources or quick-reference guides embedded in the clinical environment, support knowledge retention and application (Totenhofer et al., 2021).

Furthermore, interprofessional simulation that includes both nursing and physician teams fosters shared mental models and improves communication around device data (O'Leary et al., 2023). Mastery learning, where training continues until a predefined proficiency level is achieved, rather than for a fixed time, shows significant promise in ensuring competency is met (Barsuk et al., 2016). However, studies note significant institutional barriers, including cost, time constraints, and lack of dedicated educator resources, which often prevent the sustained implementation of these ideal models (Guise et al., 2017). A multi-pronged approach to these challenges is outlined in Table 2.

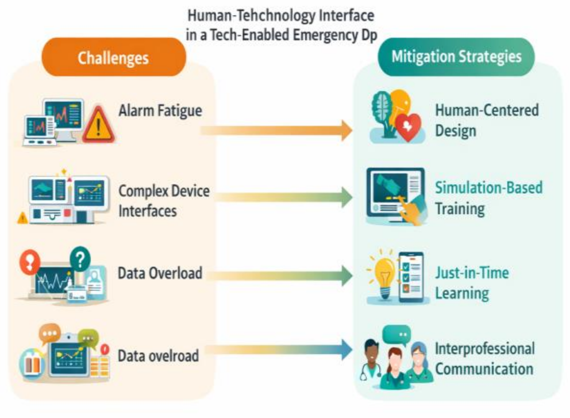

Figure 2. Human–Technology Interface Challenges and Mitigation Strategies in the Tech-Enabled ED

Table 2: Strategies to Mitigate Key Challenges at the Human-Tech Interface

Challenge	Training/Educational Strategy	System/Design Strategy
Alarm Fatigue	Education on alarm pathophysiology and customization; scenario-based training on prioritizing alarms.	Implementation of alarm management policies; procurement of devices with intelligent, customizable alarm thresholds and delayed notification options.
Poor Usability in Crisis	High-fidelity simulation under stress; JIT guides for complex devices.	Application of Human Factors Engineering in procurement; advocating for standardized controls (e.g., knob vs. touchscreen for critical functions).
Data Interpretation Gaps	Interprofessional case reviews focusing on device data; mastery learning for waveform interpretation.	Integration of device data into unified electronic health record displays with trend visualization; structured communication tools (e.g., SBAR) for device data escalation.
Skill Decay	Regular low-dose, high-frequency simulation drills; competency-based assessment cycles.	Creation of a dedicated device educator role; development of peer-led support networks for device experts on each shift.

The Impact on Patient Safety

The ultimate metric for evaluating competency and design is patient safety. The evidence draws clear, if multifaceted, connections. Inadequate competency and poor design contribute to medication errors via infusion pump misprogramming (Schnock et al., 2017), diagnostic delays from misinterpreted monitoring data (Edelson et al., 2008), and treatment complications, such as ventilator-associated lung injury from improper settings management (Blakeman, 2013). Conversely, interventions that improve competency, such as structured training programs on capnography interpretation, have been directly linked to improved detection of respiratory depression and adverse events (Lam et al., 2017).

Safety is also impacted at a systems level. Alarm fatigue contributes to a noisy, stressful environment that impairs cognitive function for all team members (Rayo & Moffatt-Bruce, 2016). Inefficient device interfaces waste precious time and increase cognitive load, pulling nursing attention away from direct patient observation (Harmon et al., 2023; Wisner et al., 2019). Therefore, investing in nursing competency and human-centered device design is not merely an educational or procurement issue; it is a foundational strategy for enhancing the overall safety climate of the ED (Rigobello et al., 2017).

Conclusion and Future Directions

This review underscores that nursing-led monitoring in the tech-enabled ED is a complex, high-stakes practice. Competency is a dynamic integration of technical skill, clinical judgment, and adaptive resilience, constantly tested by environmental pressure and often hampered by suboptimal device design. To advance patient safety, a tripartite approach is non-negotiable. First, healthcare institutions must commit to ongoing, simulation-based, and interprofessional competency programs that move beyond checkbox training. Second, clinical engineers, purchasers, and clinicians must advocate for human-centered design, using their collective voice to demand devices with intelligent alarm systems, standardized interfaces, and crisis-ready usability from manufacturers. Third, interprofessional protocols must formalize the role of nursing in device data interpretation and escalation.

Future research should focus on quantifying the return on investment of robust competency programs, developing rapid assessment tools for device usability in emergency contexts, and exploring the role of artificial intelligence in mitigating alarm fatigue and providing clinical decision support. As technology continues to evolve, the imperative is clear: the most advanced device is only as safe as the competent nurse who operates it within a well-designed system.

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