BMC Nursing

RESEARCH Open Access

Exploring ICU nurses' response to alarm management and strategies for alleviating alarm fatigue: a meta-synthesis and systematic review

Dandan Xu[1†], Fan Liu[2†], Xinbo Ding[1], Jing Ma[1], Yaxi Suo[1], Yang-Yao Peng[3], Jin Li[1*] and Xing Fu[1*]

Abstract

Background Alarm fatigue is a critical issue in intensive care units, negatively impacting nurse well-being and patient safety. Understanding nurses' experiences and management strategies is essential for developing effective interventions.

Objective This study aims to elucidate the current practices of nurses in responding to alarms and their experiences with alarm fatigue.

Methods We conducted a systematic review and meta-synthesis of qualitative studies. PubMed, Embase, CINAHL, PsycINFO, Web of Science, Cochrane Library, and Wiley databases were searched from inception to May 2024. The search syntax included the following keywords and Boolean operators: ("alarm fatigue" OR "alarm management" OR "clinical alarm") AND ("ICU nurses" OR "critical care nurses" OR "intensive care nurses") AND ("experiences" OR "perceptions" OR "strategies" OR "interventions"). Eligible studies included qualitative research exploring ICU nurses' experiences and responses to alarm fatigue. The risk of bias was assessed independently by two researchers using the CASP (Critical Appraisal Skills Programme) Qualitative Research Checklist. Studies were categorized as high, medium, or low reliability based on their adherence to the CASP criteria. Data were analyzed using thematic synthesis.

Results Of 460 identified records, 11 studies met the inclusion criteria, all of which demonstrated high methodological quality. The synthesis yielded nine key findings organized into three main themes: (1) Adverse outcomes of frequent alarms. (2) Causes of alarm fatigue. (3) Effective strategies to manage alarm fatigue. Frequent ICU alarms increase nurse workload, erode alarm system trust, heighten alarm fatigue, and endanger patient safety.

Conclusion To address ICU alarm fatigue, interventions should focus on reducing false alarms, enhancing alarm reliability, strengthening nurse training, optimizing work environments, and providing psychological support. These

†Dandan Xu and Fan Liu contributed equally to this work.

*Correspondence:
Jin Li
506388872@qq.com
Xing Fu
fuxing0525@163.com

Full list of author information is available at the end of the article

measures are crucial for improving patient safety and nurse well-being. Future research should explore the long-term impact of these interventions.

Registration PROSPERO CRD42024539569.

Keywords Intensive care units, Nurse, Alarm fatigue, Alarm management, Qualitative study

Introduction

Alarms are highly prevalent in the intensive care unit (ICU). Over the past 30 years, the number of medical devices equipped with alarm functions has nearly quadrupled [1]. The purpose of these alarms is to alert healthcare providers to changes in patient conditions and to maintain patient safety. During a single shift, healthcare personnel may be exposed to as many as 1000 device alarms [2]. Ruskin's research indicates that 70-90% of these alarms are false alarms [2], triggered by patient movement, changes in positioning, staff actions, or poorly placed sensors, which do not reflect the patient's true physiological status. The substantial volume of false and non-actionable alarms wastes nurses' time and energy, potentially leading to desensitization to genuine emergency alerts. Casey's study found that 90% of nurses report frequent non-actionable alarms that disrupt patient care and diminish trust in alarm systems [3]. Concurrently, this increases the workload for healthcare providers [4]. Excessive erroneous and non-actionable alarms can desensitize healthcare providers, increasing the likelihood of missing critical alerts [4]. Consequently, providers may silence alarms or overlook important ones, posing risks to patient safety. In 2007, the Emergency Care Research Institute (ECRI), a leading U.S. medical equipment evaluation organization, first included alarms in its "Top 10 Health Technology Hazards". Alarm safety concerns have remained the top hazard on this list for four consecutive years [1].

Alarm fatigue, as a significant concern for patient safety, has received considerable attention. It refers to healthcare personnel becoming desensitized to alarm signals over time, resulting in delayed or ignored responses to alarm sounds from medical devices [5]. Working in environments with a high volume of alarms over extended periods can lead to psychological and physiological fatigue among nurses [6], impairing job efficiency and decision-making accuracy, thereby exacerbating risks to patient safety. Healthcare providers may mitigate alarm fatigue by reducing alarm volumes, silencing alarms, and delaying responses to alarms [4, 7]. Failure to respond promptly to alarms can prolong hospital stays or even result in patient mortality [8]. Furthermore, research by Nyarko et al. demonstrates a significant association between alarm fatigue and intensive care nurses' occupational burnout, with increased alarm fatigue correlating with higher levels of burnout [9].

Nurses play a primary role in managing alarms and it is essential to clarify their experiences in responding to alarms and alarm fatigue. Experienced nurses are capable of accurately assessing the importance of alarms [4], thereby avoiding excessive responses to unnecessary alarms while ensuring prompt and correct responses to genuine emergencies. This experience also helps nurses mitigate the risk of alarm fatigue by enabling them to manage and filter alarm information more effectively, thus maintaining sensitivity to critical alarms. Unlike non-ICU nurses, ICU nurses are exposed to alarms extensively, responding to between 150 and 400 alarms per patient per day [10]. Their perspectives directly reflect the effectiveness and practicality of alarm systems. In Casey's cross-sectional study [3], most nurses understood the causes of alarm fatigue, but 52% were unsure how to prevent it. Therefore, by sharing and clarifying experiences in addressing alarm fatigue, managers can better understand nurses' work conditions and take appropriate measures to optimize workflow and alarm system settings, thereby enhancing nursing quality and patient safety. Thus, the aim of this study is to elucidate the current practices of nurses in responding to alarms and their experiences with alarm fatigue.

Methods

Study design

A qualitative meta-synthesis was conducted to explore ICU nurses's experiences with alarm fatigue. Qualitative methods are particularly well-suited for exploring nurses' subjective experiences, as they allow for an in-depth understanding of their perspectives, emotions, and contextual factors—elements that are difficult to capture through quantitative methods such as meta-analysis. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used for study selection. The protocol for this systematic review was prospectively registered with PROSPERO (registration number: CRD42024539569). The research process included the following steps: (1) defining the research question, (2) systematically searching relevant studies, (3) screening, selecting, and critically evaluating articles, (4) data extraction, and (5) presenting data analysis and qualitative synthesis.

Inclusion and exclusion criteria

Inclusion criteria: (1) Study participants are ICU nurses. (2) Nurses have experienced alarm fatigue. (3) Studies utilize qualitative methods, including the qualitative component of mixed-methods research. (4) Studies published before May 2024. Exclusion criteria: (1) Non-English articles. (2) Duplicate publications. (3) Articles without full-text availability.

Search strategy

To comprehensively understand ICU nurses' experiences with alarm fatigue, we searched multiple databases including PubMed, Embase, CINAHL, PsycINFO, Web of Science, Cochrane Library, and Wiley. The literature search was conducted from the inception of each database up to May 2024. Search terms included: "alarm fatigue", "clinical alarm", "intensive care unit", "nurse", "experience". The specific retrieval strategies can be referred to in the supplementary material.

Screening and selection of included studies

The article selection process was conducted independently by two researchers to ensure accuracy and consistency. During the initial screening, we used NoteExpress, a reference management software, to identify and remove duplicate records. The screening process followed the PRISMA guidelines and included the following steps: (1) Initial screening of titles and abstracts to exclude irrelevant studies. (2) Full-text review of potentially eligible articles to assess their relevance and quality. (3) Final inclusion of studies that met the predefined criteria.

Quality assessment

Two researchers independently evaluated the quality of included articles using the CASP Qualitative Research Checklist [11]. Studies were categorized based on their reliability using the CASP Qualitative Research Checklist: high reliability for studies that met al.l or most of the CASP criteria, medium reliability for studies that met some criteria but had minor limitations, and low reliability for studies that met few or none of the criteria. Any discrepancies were resolved through discussion, and if necessary, referred to a third reviewer.

Data extraction and synthesis

The search results were imported into NoteExpress, where two researchers independently screened literature and extracted data. Any discrepancies were resolved by a third researcher. Information such as study objectives, participant characteristics, data collection methods, and study designs were entered into Microsoft Excel. Data synthesis was conducted using thematic synthesis [12], following the PRISMA guidelines. The synthesis involved three stages: (1) Coding the text. (2) Developing descriptive themes, and (3) generating analytical themes to produce higher-order themes that transcend primary study findings. We analyzed raw data from each individual study included in this research, comprehensively understanding original study results through repeated readings of the literature and summarizing similar findings to form new categories.

Results

Search results

The study selection process followed the PRISMA guidelines and is summarized in Fig. 1. A total of 460 records were screened. After removing 164 duplicate records using NoteExpress software, 296 unique records remained for title and abstract screening. During the initial screening, 257 records were excluded as they did not meet the inclusion criteria (e.g., irrelevant topics, non-ICU settings, or non-qualitative studies). The remaining 39 full-text articles were assessed for eligibility. Of these, 28 articles were excluded. Finally, 11 studies met the inclusion criteria and were included in the qualitative synthesis.

Article characteristics

We included a total of 11 articles, comprising phenomenological studies [6, 13–20] ($n = 9$) and grounded theory studies [21, 22] ($n = 2$). This includes parts of qualitative studies from three mixed-methods studies [15, 18, 20]. Most studies employed thematic analysis, detailed in Table 1. Our research encompassed the experiences of 249 nurses, the majority from intensive care units, with a small portion from pediatric intensive care units.

Quality assessment

The quality assessment indicated that all 11 included studies demonstrated high quality, with minor variations observed. Notably, most studies did not provide documentation regarding the relationships between researchers and participants, which may have implications for potential biases. The quality assessment results are summarized in Table 2.

Integration of qualitative research data

Based on the findings, three main themes and eight subthemes were integrated. The three main themes include: (1) Adverse outcomes of frequent alarms. (2) Causes of alarm fatigue. (3) Effective strategies to manage alarm fatigue. Table 3 provides a clear overview of the key themes and subthemes identified in the synthesis, along with the supporting studies.

Adverse outcomes of frequent alarms

Increased nurse workload Frequent alarms not only significantly increase nurses' workload but also linger as per-

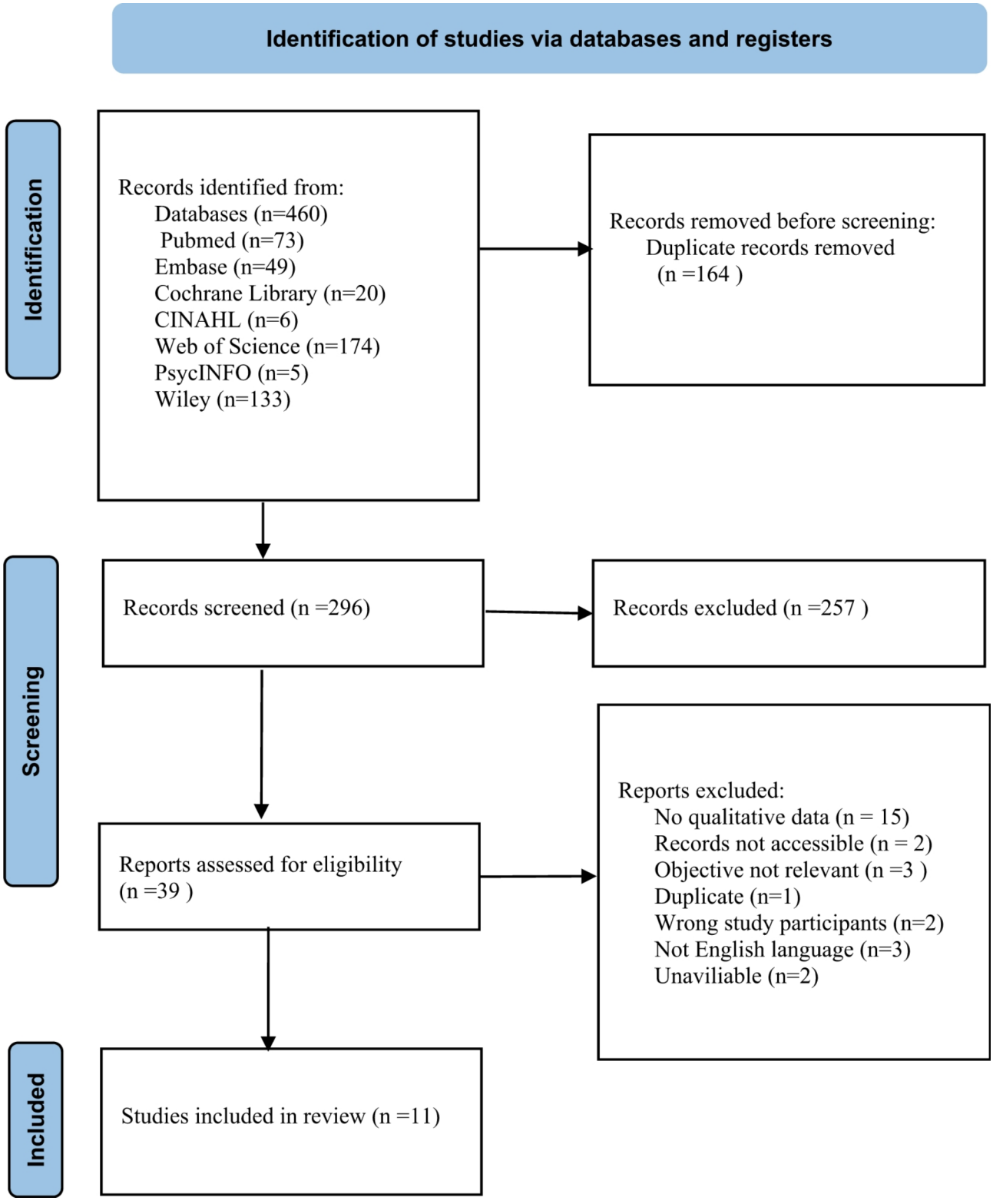

Fig. 1 Flow diagram of studies included and excluded at each stage of review

Table 1 Summary of included studies

Author (first), year	Country	Aim	Setting	Participants	Methods	Findings (Themes)
Movahedi [6] (2023)	Iranian	To explore strategies used by nurses in dealing with nurses' alarm fatigue in the intensive care unit (ICU).	Online and telephone	Eighteen nurses	Content analysis	1. Technologic actions. 2. Non-technologic actions.
Movahedi [21] (2023)	Iranian	To explore the process of how nurses experienced and dealt with alarm fatigue in intensive care units based on Iranian nurses' perceptions and experiences.	In an office	Twenty nurses	Grounded theory	1. The main concern. 2. The context. 3. The process: trying to create a holistic balance. 4. The outcomes of the process. 5. Brief storyline.
López-Espuela [13] (2022)	Spanish	To explore the experiences and mediating factors of nurses' responsaes to electronic device alarms in critical care units.	In an office	Seventeen nurses	Content analysis	1.General perceptions about alarms 2.Strategies to reduce false alarms 3.Key elements of the response to alarms
Shih [14] (2022)	China	To investigate critical care nurses' perceptions of clinical alarm management and its impact on their daily practice.	In an office	37 nurses	Content analysis	1. The foundation of critical care practice. 2. A trajectory of adjust alarms management. 3. Negative impacts on care quality and patient safety. 4. Hope for remote control and multimodal learning.
Akturan [15] (2022)	Turkey	To reveal the existence of alarms in COVID-19 intensive care units, where medical devices with alarm function are frequently used, the effects of alarms on nurses, especially their on-the-job performances and social lives, and their coping methods.	In an office	Eighteen nurses	Content analysis	1. COVID-19 service work environment factors affecting alarm fatigue. 2. Situations that determine nurses' responses to alarms. 3. Coping strategies against alarms. 4. Suggestions for reducing alarm fatigue. 5. The effects of alarm fatigue on social life.
Simpson [16] (2019)	USA	To explore similarities and differences in perceptions of clinical alarms by labor nurses caring for generally healthy women compared with perceptions of adult ICU and neonatal ICU (NICU) nurses caring for critically ill patients and to seek nurses' suggestions for potential improvements.	Unclear	33 nurse	Thematic analysis approach	1. Alarm fatigue. 2. Impact of alarms on patients and family. 3. Implications for patient safety. 4. Suggestions for improvement.
Ruppel [17] (2019)	USA	To explore clinical reasoning about alarm customisation among nurses in intensive care units.	Telephone	Twenty-seven nurses	Thematic analysis approach	1.Unit alarm culture and context. 2. Nurse attributes. 3.Motivation to customise. 4.Customisation "Know-How".
Poncette [22] (2019)	German	To explore desires, concerns, and perceived challenges of ICU staff on patient monitoring that may stimulate rapid and sustainable technological adaption in the ICU.	Unclear	Six nurses	Thematic analysis approach	1. Current patient monitoring. 2. Future patient monitoring. 3. Barriers to implementation of novel patient monitoring.
Ruppel [18] (2018)	USA	To understand ICU nurses' approaches to customization of electrocardiographic (ECG) monitor alarms.	Telephone	Twenty-seven nurses	Thematic analysis approach	1. Unit alarm culture and context. 2. Nurse attributes. 3. Motivation to customize. 4. Customization "know-how."

Table 1 (continued)

Author (first), year	Country	Aim	Setting	Participants	Methods	Findings (Themes)
Despins [19] (2017)	USA	To examine what prompts the ICU nurse to proceed to the patient's bedside in response to an alarm and the influences on the nurse's perception regarding how quickly this needs to occur.	An private office	Twenty-four nurses	Thematic analysis approach	1. Catching patient deterioration. 2. Determining the immediacy of patient risk of harm. 3. Prioritizing true alarms.
Sowan [20] (2015)	USA	To determine perceptions and practices of transplant/cardiac ICU (TCICU) nurses toward clinical alarms and benchmark the results against the 2011 Healthcare Technology Foundation's (HTF) Clinical Alarms Committee Survey.	E-mail	Twenty-two nurses	Thematic analysis approach	1.Frequent false alarms and patient safety 2.Poor usability of the medical devices 3. Lack of support to the use of evidence-based solutions for alarm management 4.Unit-related factors to alarm management

sistent shadows after their shifts, troubling their mental well-being. This ongoing disruption and heightened state of tension reduce nurses' sensitivity to genuine emergency alarms over time, potentially leading to instances where alarms are ignored.

Work interruptions. *"I had a very sick patient. I wanted to write my report in the patient's file, but the alarm for another patient sounded. I could not be indifferent and I had to fix it. But I fall behind of my own work schedule* [21]. *".*

Physical fatigue. *"While one nurse is for 2 patients in other intensive care units, one nurse for 3 patients in the COVID-19 service, which makes us exhausted and forces our tolerance limit while working in the service* [15]*."*

Mental distress. *"When you go home at night, you can still hear it all" and "Sometimes I dream about dings* [16]*."*

Decreased sensitivity. *"I cannot make it to always react to alarms. When I am more in touch with something, I lose my sensitivity to it. I try not to pay attention to the alarm so that it does not bother me* [21]*."*

Ignoring alarms. *"I have watched multiple nurses at the nursing desk listen to alarms sounding and not respond, very worrisome* [20]*."*

Patient's mental and physical damage Due to frequent alarm sounds, patients often struggle to get adequate rest at night. These continuous noises not only disrupt patients' sleep but also create a tense and fearful atmosphere in the ICU environment. Worse still, when nurses begin to overlook certain alarms due to their frequency, they may miss genuine emergency alerts, posing significant threats to patient safety.

Insomnia. *"Especially in the surgical ICU, where patients were alert, they became nervous, because the alarm could ring in the middle of the night or at any time. Patients had insomnia* [21]*."*

Anxiety. *"Visitors get upset that you're not responding to the alarms quick enough, but we know there is nothing wrong* [16]*."*

Fear. "The device rings an alarm, and that flashing light [points to the device] is the source of horror and stress to the patient [6]*."*

Threatening patient safety. *"I have to admit that once my patient had repeated false alarms of low oxygen saturation for a few days but did not require any immediate care intervention. So when it had alarmed, I thought it was the same (false alarm) again[horizontal ellipsis] so I continued the care task at hand and sent out the blood sample first and then checked that patient, but then I found the patient was cyanotic* [6]*."*

Table 2 Methodological assessment

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Movahedi [6] (2023)	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
Movahedi [21] (2023)	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
López-Espuela [13] (2022)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Shih [14] (2022)	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
Akturan [15] (2022)	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
Simpson [16] (2019)	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
Ruppel [17] (2019)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Poncette [22] (2019)	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
Ruppel [18] (2018)	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
Despins [19] (2017)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Sowan [20] (2015)	Y	Y	Y	Y	Y	N	Y	Y	Y	Y

The CASP tool assesses the quality and usefulness of research studies with a ten-question survey. The questions are: Q1 Was there a clear statement of aims? Q2 Is the methodology appropriate? Q3 Was the research design appropriate to address the aims? Q4 Was the recruitment strategy appropriate to the aims of the research? Q5 Were the data collected in a way that addressed the research issue? Q6 Has the relationship between the researcher and participants been considered? Q7 Have ethical issues been taken into consideration? Q8 Was the data analysis sufficiently rigorous? Q9 Is there a clear statement of findings? Q10 How valuable is the research? *Critical appraisal ($n = 11$ of (Y = yes; N = no; U = unclear; NA = not applicable)

Table 3 Synthesized themes and subthemes on ICU nurses' management of and responses to alarm fatigue

Theme	Subtheme	Studies
Adverse outcomes of frequent alarms	Increased nurse workload	López-Espuela [13], Shih [14], Akturan [15], Simpson [16], Ruppel [17], Ruppel [18], Sowan [20], Movahedi [21], Poncette [22]
	Patient's mental and physical damage	Movahedi [6], López-Espuela [13], Shih [14], Akturan [15], Simpson [16], Despins [19], Sowan [20], Movahedi [21], Poncette [22]
Causes of alarm fatigue	High volume of clinical alarm information	López-Espuela [13], Akturan [15], Simpson [16], Ruppel [18], Despins [19], Sowan [20], Movahedi [21]
	Lack of standardized clinical alarm management	López-Espuela [13], Shih [14], Akturan [15], Ruppel [17], Poncette [22]
	Poor medical equipment availability	López-Espuela [13], Akturan [15], Ruppel [18], Movahedi [21], Poncette [22]
	Staff shortage	López-Espuela [13], Akturan [15], Ruppel [17]
Effective strategies to manage alarm fatigue	Alarm management and optimization	Movahedi [6], López-Espuela [13], Akturan [15], Ruppel [17], Ruppel [18], Despins [19], Sowan [20], Movahedi [21], Poncette [22]
	Team collaboration and personnel training	Movahedi [6], López-Espuela [13], Shih [14], Ruppel [17], Sowan [20], Poncette [22]
	Environment optimization and self-regulation driven by technology	Movahedi [6], López-Espuela [13], Shih [14], Akturan [15], Ruppel [17], Sowan [20], Movahedi [21], Poncette [22]

Causes of alarm fatigue

High volume of clinical alarm information Nurses easily develop fatigue towards alarm systems due to frequent and often false alarms. This fatigue stems from the repetitive handling of invalid information and prolonged periods of heightened tension, leading to significant psychological stress. When fatigue causes them to miss genuine emergency alarms, the consequences for patient harm are particularly severe. In such cases, nurses may experience post-traumatic stress disorder, severely impacting their work efficiency and mental health.

Post-traumatic stress disorder. *"Some of the nurses with more experience refuse to turn off any alarm because they've seen so much, and something strange has happened, they've had an acute event that's bizarre and … [they] have PTSD [post-traumatic stress disorder] and refuse to turn off alarms* [18]*."*

False alarms. *"The excess number of so many false alarms cause the staff to be careless … like the famous wolf story, right? (cry-wolf phenomenon) … the alarm is beeping all the time and you have already got up a thousand times, of course …* [13]*".*

Fatigue. *"It was awful. I went to assess the patient and I said to myself I wish I had come earlier, I wish that I had not left the patient and had checked him at the beginning of the work shift. I felt that I did not do my job properly and I failed* [21]*."*

Frequent alarms. *"Everything alarms in the NICU: our ventilators alarm, our IV pumps alarm. Alarms are going off constantly," and "The phones are ringing, IVs are going, vents going, regular alarms going, the tube station and tube feeding beep. It's just too much* [16]*."*

Lack of standardized clinical alarm management In clinical practice, alarm systems are often set without standardized protocols, with thresholds adjusted inconsistently. Such non-standardized settings not only disturb patients' nighttime rest but also present numerous challenges to healthcare professionals. For new nurses, insufficient understanding and experience with alarm systems often result in decreased sensitivity to alarms. This may lead to delays in identifying and addressing critical alarm signals promptly. Additionally, it's notable that apart from nurses, other physicians also pay minimal attention to alarms. This could be attributed to doctors focusing more on diagnosis and treatment, thus underestimating the importance of alarm systems. However, this disregard may overlook potential safety hazards, thereby increasing patient risks.

Alarm configuration. *"Alarm management is rather a big problem in the intensive care unit; some people set the alarm limits very tightly, which often leads to false alarms. I think it's important to work on the alarm management within the team.especially at night, also the sound for the patients. When the patient is supposed to sleep and then the monitor beeps all the time.* [22]*".*

Inexperienced new nurses. *"During the orientation phase, I was wondering why I could not hear the alarm of my patient? Why I was unable to distinguish between the different sounds and handle problems in the ways that my coworkers did* [14]*?"*

Doctors and other unit staff often pay little attention to alarms.*"… It's like they are only there for probably 10 minutes during rounds … but you're at the bedside the entire shift. You know what's going on, that's my room, that's my patient* [17]*."*

Poor medical equipment availability Some medical equipment technologies are unreliable, and the designs of certain monitoring devices appear inadequate. These issues have serious consequences in practical operation, particularly with frequent and difficult-to-correct false alarms.

Unreliable alarm integration technology. *"CISCO phones and pagers sometimes don't alert or receive any alarms even for emergencies, there are delays on them and they loose the signals in the elevators* [20]*."*

Inability to correct false alarms. *"The frustration with that is sometimes some other arrhythmias mimic V-tach [ventricular tachycardia] on the monitor. Like, a bundle branch block will look like a wide complex tachycardia and this is where you come into the most frustrating part where you constantly have false alarms but you can't shut off the V-tach alarm … it is so noisy and frustrating* [18]*."*

Poorly designed monitoring devices. *"the new cardiac monitors have the same volume alarm for even the most trivial alarms that it sets a cry wolf mentality and could pose a dangerous situation in which an actual true alarm could be disregarded* [20]*."*

Staff shortage Insufficient personnel means that healthcare teams face tremendous pressure in handling daily tasks, especially during urgent situations requiring rapid response. Due to limited manpower, healthcare providers may not be able to fully attend to every alarm, thereby increasing the risk of missed alarms or delayed responses.

Overwhelmed by tasks.*"I think there's a direct correlation between staffing and appropriate patient assignments and alarms … people don't have the time to address [alarms] when they're swamped with their assignment …* [17]*".*

Staff shortage. *"… Sometimes it happens that there are fewer nurses on shift and there is an emergency, and we are attending to that emergency … and of course, it's not that we have neglected the alarms of other patients, it's just that there are less staff and we can't cope* [13]*."*

Effective strategies to manage alarm fatigue

Alarm management and optimization To ensure patient safety, nurses customize alarm thresholds based on individual patient conditions. The aim is to reduce unnecessary alarms that may disrupt normal nursing workflows by adjusting trigger conditions. When alarms occur, nurses prioritize them based on their nature, severity, and potential impact on patients to ensure swift responses during emergencies. Moreover, nurses rely on their professional knowledge and clinical experience to assess the validity of alarms, enhancing sensitivity to real alarms and reducing resource waste and decreased nursing efficiency due to false alarms. Once a genuine alarm is identified, nurses promptly initiate proactive interventions. They utilize their expertise, skills, and past experi-

ences to determine the cause of the alarm and develop appropriate nursing plans accordingly.

Personalized Alarm Settings. *"After getting acquainted with the ward routine, I realized that some equipment were set to suit the previous patient's health condition. It was necessary to change the alarm's threshold and later I learned that for every patient, such adjustments must be made. I felt more comfortable and had less stress* [6]*."*

Handling according to alarm priority levels. *"To be able to determine if an alarm is an urgent matter, you must know what the patient's condition is. In the most critical patients, we normally have all five senses on them, we do not wait for the second warning from the monitor. As soon as you hear the first sound you attend, you do not wait, always depending on the seriousness of each one of them* [13]*."*

Prompt processing. *"...if the person's on dialysis there's alarms associated with dialysis. Those have to be responded to quickly because you don't want that blood clotting off... that's a lot of blood loss* [19]*."*

Preparation based on experience. *"If I find that the syringe pump is finished, I prepare the alternative syringe. As soon as the alarm rings, the medicine becomes ready. I always check the syringe pump before it is finished to reduce unnecessary alarms* [6]*."*

Team collaboration and personnel training In their daily management of multiple patients, nurses frequently encounter alarms from various medical devices. When faced with alarms that cannot be addressed immediately, other team members swiftly intervene to assist nurses in managing these urgent situations, ensuring timely attention to patient safety and health. However, nurses realize that relying solely on temporary assistance from team members is not a sustainable solution, especially when false alarms occur frequently. To better manage these alarms effectively, nurses widely agree on the necessity of receiving specialized training and education in alarm management. They advocate for utilizing practical opportunities in their work environment and peer education to acquire skills in alarm management.

Team collaboration. *"We work a lot as a team because we also know all the patients in the unit … and we help each other … if I'm with another patient, and I can't get out of the box, I call a colleague, please check out what it is sounding …* [13]*".*

Training. *"If I had more time, then I would like to have more functions [in patient monitoring] and we must be trained more intensively for using the new [medical] devices* [22]*."*

Peer education. *"When someone new comes in, there is no time for formal training, but rather they acquire knowledge as they work and the colleagues teach them during the working day …* [13]*".*

Environment optimization and self-regulation driven by technology Introducing new technologies to reduce false alarms from medical devices, collaborating closely with engineers to address alarm issues. Simultaneously, ensuring nurses receive adequate rest and proper nutrition after shifts to overcome the physical and mental fatigue caused by alarms.

Support from equipment personnel. *"Another thing that was very useful to me was that the medical equipment engineer explained a series of alarms and functions of the device to me. He provided direct support to me* [6]*."*

Improving technology. *"I absolutely believe it [remote patient monitoring] is a step in the right direction. It benefits the patients, after all. And in the best case, it makes the work easier* [22]*."*

Self-regulation. *"I come to work with peace and have good nutrition and good energy before coming to my workplace. I always try to come with the maximum energy when I want to come here, whether nutritionally, physically, or mentally* [6]*."*

Improving conditions. *"There is a conscious patient who has a patient next to him under the ventilator and with frequent alarms. The patient gets really nervous, I have a patient who is crying! I try to move the patient's bed to another place* [6]*."*

Discussion

This study systematically synthesized and reviewed 11 qualitative studies to deeply understand the current practices of ICU nurses in responding to alarms and their experiences with alarm fatigue. The research elaborates on the adverse consequences of alarm fatigue, including the potential threats to patient safety and the psychological and physical toll on nurses, who are often considered the secondary victims. By exploring the origins of alarm fatigue among ICU nurses and their strategies to manage it, this study provides a basis for developing targeted interventions. These interventions aim to effectively alleviate nurse alarm fatigue, improve work efficiency, and ensure patient safety.

Our study explored the multiple impacts of alarm fatigue on patient safety and the physical and mental health of nurses. For awake patients, frequent and unnecessary alarms not only exacerbate their anxiety and mental stress, but also further intensify their psychological pressure within the already highly stressful ICU environment [16]. A recent study indicated [23] that nighttime monitor alarms reached 53.6 decibels, with false alarms being the primary source of noise. Najafi's research demonstrated that these frequent alarms significantly disrupt patients' sleep quality and increase the incidence of

delirium [24]. Seifert found in their study that over 80% of alarms were false alarms [25]. This phenomenon not only increases nurses' workload but may also lead to frequent interruptions in their workflow. The abundance of false alarms may prompt nurses to either silence alarms or widen alarm thresholds [21]. ICU nurses, continuously exposed to increasing non-actionable alarms, gradually extend their response times to subsequent alarms. Bonafide's findings [26] indicate that during nurse shifts, for every hour passed, alarm response times increase by 6%. Nurses' disregard or exaggerated response to alarm signals may pose potential threats to patient safety. Nurses may inadvertently miss important alarm information, leading to adverse events. As indirect victims of these events, they are susceptible to developing post-traumatic stress disorder. To avoid missing any critical information, nurses may opt to keep all alarm settings active [18]. In our study, nurses indicated that they are often overwhelmed by the volume of alarm sounds during their daily work. This continuous auditory stimulation may leave them feeling exhausted even after their shift ends, and they may still feel surrounded by alarm sounds, making it difficult to relax and rest.

In managing nurse responses to alarm fatigue, ICUs face unique challenges. Despite guidelines from the American Association of Critical-Care Nurses and The Association for the Advancement of Medical Instrumentation on alarm management [27, 28], there is a lack of standardized guidance for setting alarm thresholds [29, 30], leading to inappropriate adjustments. Particularly at night, frequent alarms disrupt patient rest and increase nurse workload. Cho's study [31] showed that alarm thresholds often remain unchanged or are set to default, lacking both personalization and standardization. Recent research has explored adaptive alarm strategies based on threshold analysis using big data to issue timely alerts during adverse events [32]. In our study, inexperienced nurses tend to overlook alarm information. A cross-sectional study indicated that 63.5% of nurses reported no specific alarm training beyond basic device operation guidance [9]. For new nurses, insufficient experience and training lead to inadequate appreciation of alarm system importance, resulting in reduced sensitivity to alarms [4]. This insensitivity may cause them to miss critical medical alerts, posing risks to patient safety. Our research found that doctors also pay scant attention to alarm systems and rely on nurses to manage these issues, consistent with prior studies [33]. This disregard may lead to crucial medical information being overlooked, thereby increasing patient risks. Therefore, managers need to enhance training and education for both doctors and nurses to improve their alarm sensitivity. Additionally, promoting awareness and education among existing healthcare staff is crucial to ensure timely and accurate responses to alarm information.

Insufficient availability of medical equipment further exacerbates ICU nurses' alarm fatigue [20]. Sowan's study highlighted nurses' concerns about unreliable mobile devices, which sometimes experience delays or signal loss [20]. Unreliable alarm integration technology leads to persistent false alarms that are difficult to rectify easily. These false alarms not only undermine nurses' trust in the alarm system but also increase their cognitive load as they must discern genuine from false alarms amidst numerous notifications. Machine learning algorithms have been developed to construct predictive models supporting false alarm correction [34, 35], but their widespread clinical application and reliability require further investigation. Staff shortages exacerbate these challenges; with inadequate staffing, nurses may struggle to prioritize alarm responses effectively, potentially delaying critical interventions and affecting patient outcomes.

In this study, ICU nurses' experiences in managing alarm fatigue provide valuable practical guidance for clinical alarm management. Currently, there is a lack of threshold-based adaptive alarm instruments. Experienced nurses adjust alarm sensitivity and specificity based on patients' underlying conditions and physiological monitoring data. Shanmugham's research [36] demonstrated that modifying clinical alarm thresholds according to patients' clinical status reduces nurses' workload compared to unchanged default settings. Experienced nurses prioritize alarm handling based on patient conditions more effectively than new nurses. Nyarko's study [9] revealed that nurses with longer tenures typically exhibit lower levels of alarm fatigue, likely due to their extensive practical experience and profound understanding of the work environment. Our research underscores the importance of teamwork. Establishing clear communication channels and shared decision-making processes can effectively reduce misunderstandings in information transmission and repetitive tasks in alarm handling, thereby enhancing overall team response efficiency. In Dandoy et al.'s study [37], team-based cardiac monitor nursing protocols significantly reduced alarm frequency. Regular team training and peer education are also crucial strategies. Through simulations and case studies, nurses gain better insights into and responses to various alarm challenges, thereby enhancing team adaptability and collaborative efficiency. As emphasized by Ruppel [38], only regular training ensures safe and correct use of monitors and reduces alarm fatigue. Training should be comprehensive, covering not only basic instrument functions but also advanced features. Concurrently, peer education programs facilitate experience sharing and practical exchanges among nurses, helping both new

and experienced nurses better handle the challenges and pressures of alarm management.

AI-supported systems are useful [39], as nurses need intelligent devices for remote patient monitoring and optimized alarm management, aligning with our findings. Combining intelligent alarm management tools or systems with evidence-based interventions effectively improves nurses' alarm management behaviors [37]. However, the extent to which intelligent alarm management measures reduce alarm frequency remains uncertain. In Ruppel's study [40], nurses expressed concerns about introducing new technologies due to their already heavy patient care responsibilities and fears of increased workload. Therefore, effective implementation of intelligent monitoring that does not add to nurses' workload requires further exploration. Our study indicates that high-frequency alarms affect nurses' physical and mental health. They manage this through effective self-management and emotional regulation techniques such as deep breathing, relaxation training, and regular psychological support [6]. Furthermore, support from hospital management and encouragement of professional development help nurses enhance job satisfaction and coping abilities, thereby reducing the negative impact of alarm fatigue on individual health and work efficiency.

Impact on cinical practice

This study has profoundly influenced clinical practice. By integrating multiple research findings, the study reveals the potential threats of alarm fatigue to nurses' work efficiency and patient safety, and identifies key factors contributing to alarm fatigue. This not only enhances healthcare professionals' awareness of alarm fatigue issues but also provides specific guidance for healthcare institutions to improve alarm systems and optimize nurses' work environments and processes. Furthermore, the study emphasizes the critical role of nurses in managing alarm fatigue, promoting interdisciplinary collaboration and technological innovation. It aims to effectively reduce nurses' levels of alarm fatigue through technological innovations and training education, thereby enhancing healthcare quality and patient safety.

Limitations

While meta-integration allows for the synthesis of results from multiple studies, this research is based on interview data collection and lacks direct experimental evidence, which may introduce some subjectivity and bias. Additionally, differences in healthcare systems and cultural backgrounds across countries and regions may lead to variations in ICU nurses' perception of and experiences with alarm fatigue. This study may not fully encompass all cultural and regional differences. Therefore, when applying the study conclusions to clinical practice, it is necessary to consider various factors comprehensively and make appropriate adjustments and supplements.

Conclusion

This study systematically integrates multiple independent studies, providing robust evidence on ICU nurses' perception of and responses to alarm fatigue. Through rigorous screening and evaluation, the research ensures reliability and effectiveness. The findings not only reveal the causes and influencing factors of alarm fatigue but also propose practical coping strategies, offering valuable guidance for clinical practice. Despite ICU nurses' deep understanding of the benefits of clinical alarms for patient safety, frequent alarms impose significant burdens, leading to decreased trust in alarm systems, increased alarm fatigue, and potential risks to patient safety. Alarm fatigue, a prevalent issue among ICU nurses, threatens their physical and mental well-being as well as patient outcomes. This study summarizes nurses' experiences and strategies in managing alarm fatigue, including reducing unnecessary alarms, enhancing alarm credibility, strengthening training, and improving the work environment. Additionally, psychological interventions are needed to mitigate the impact of alarm fatigue on nurses. Immediate priorities include improving the performance and usability of clinical alarm systems to maximize patient safety, standardizing comprehensive alarm management, and monitoring nurses' stress levels to provide necessary support. Future research should focus on developing advanced alarm algorithms, exploring the long-term effects of alarm fatigue on nurses' health and performance, investigating organizational and environmental factors influencing alarm management, and assessing the effectiveness of psychological support programs in addressing alarm fatigue.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12912-025-03084-y.

Supplementary Material 1

Author contributions

DD X and F L: Writing - Original Draft, Conceptualization, Methodology. XB D and J M: Data Curation, Supervision. YX S and YYP: Visualization, Formal analysis. X F and J L: Conceptualization, Methodology, Writing - Review & Editing. All authors read and approved the final manuscript.

Funding

This study received no external funding.

Data availability

Data is provided within the manuscript or supplementary information files.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Department of Critical Care Medicine, Zhongnan Hospital of Wuhan University, Clinical Research Center of Hubei Critical Care Medicine, Wuhan, Hubei 430071, China
[2]Nursing Department, Huangmei County People's Hospital, Huangmei, China
[3]Department of Neurosurgical Intensive Care Unit, Zhongnan Hospital of Wuhan University, Wuhan, China

Received: 10 February 2025 / Accepted: 8 April 2025
Published online: 11 April 2025

References

1. Hayhurst C, Right, Alert. Right time: developing clinically meaningful, actionable alarm notifications. Biomed Instrum Technol. 2020;54(1):12–20. https://doi.org/10.2345/0899-8205-54.1.12.
2. Ruskin KJ, Hueske-Kraus D. Alarm fatigue: impacts on patient safety. Curr Opin Anaesthesiol. 2015;28(6):685–90. https://doi.org/10.2345/0899-8205-54.1.1.
3. Casey S, Avalos G, Dowling M. Critical care nurses' knowledge of alarm fatigue and practices towards alarms: A multicentre study. Intensive Crit Care Nurs. 2018;48:36–41. https://doi.org/10.1016/j.iccn.2018.05.004.
4. Lewandowska K, Weisbrot M, Cieloszyk A, et al. Impact of alarm fatigue on the work of nurses in an intensive care environment-A systematic review. Int J Environ Res Public Health. 2020;17(22):1–14. https://doi.org/10.3390/ijerph17228409.
5. Sendelbach S. Alarm fatigue. Nurs Clin North Am. 2012;47(3):375–82. https://doi.org/10.1016/j.cnur.2012.05.009.
6. Movahedi A, Sadooghiasl A, Ahmadi F, et al. Smart care for dealing with nurses' alarm fatigue in the intensive care unit. J Nurs Scholarsh. 2023;55(4):825–33. https://doi.org/10.1111/jnu.12870.
7. Hravnak M, Pellathy T, Chen L, et al. A call to alarms: current state and future directions in the battle against alarm fatigue. J Electrocardiol. 2018;51(6S):44–8. https://doi.org/10.1016/j.jelectrocard.2018.07.024.
8. Sendelbach S, Funk M. Alarm fatigue: A patient safety concern. AACN Adv Crit Care. 2013;24(4):378–86. https://doi.org/10.1097/NCI.0b013e3182a903f9.
9. Nyarko BA, Yin Z, Chai X, et al. Nurses' alarm fatigue, influencing factors, and its relationship with burnout in the critical care units: A cross-sectional study. Aust Crit Care. 2024;37(2):273–80. https://doi.org/10.1016/j.aucc.2023.06.010.
10. Keller JJ. Clinical alarm hazards: A top ten health technology safety concern. J Electrocardiol. 2012;45(6):588–91. https://doi.org/10.1016/j.jelectrocard.2012.08.050.
11. Critical Appraisal Skills Programme. Checklist. 2018. Available from: https://casp-uk.b-cdn.net/wp-content/uploads/2018/01/CASP-Qualitative-Checklist-2018. Accessed July 20, 2020.
12. Thomas J, Harden A. Methods for the thematic synthesis of qualitative research in systematic reviews. BMC Med Res Methodol. 2008;8(45):1–10. https://doi.org/10.1186/1471-2288-8-45.
13. López-Espuela F, Rodríguez-Martin B, Lavado GJ, et al. Experiences and mediating factors in nurses' responses to electronic device alarms: A phenomenological study. J Nurs Manag. 2022;30(5):1303–16. https://doi.org/10.1111/jonm.13614.
14. Shih YS, Lee TT, Mills ME. Critical care nurses' perceptions of clinical alarm management on nursing practice. Comput Inf Nurs. 2022;40(6):389–95. https://doi.org/10.1097/CIN.0000000000000886.
15. Akturan S, Güner Y, Tuncel B, et al. Evaluation of alarm fatigue of nurses working in the COVID-19 intensive care service: A mixed methods study. J Clin Nurs. 2022;31(17–18):2654–62. https://doi.org/10.1111/jocn.16190.
16. Simpson KR, Lyndon A. False alarms and overmonitoring: major factors in alarm fatigue among labor nurses. J Nurs Care Qual. 2019;34(1):66–72. https://doi.org/10.1097/NCQ.0000000000000335.
17. Ruppel H, Funk M, Whittemore R, et al. Critical care nurses' clinical reasoning about physiologic monitor alarm customisation: an interpretive descriptive study. J Clin Nurs. 2019;28(15–16):3033–41. https://doi.org/10.1111/jocn.14866.
18. Ruppel H, Funk M, Kennedy HP, et al. Challenges of customizing electrocardiography alarms in intensive care units: A mixed methods study. Heart Lung. 2018;47(5):502–8. https://doi.org/10.1016/j.hrtlng.2018.06.010.
19. Despins LA. Factors influencing when intensive care unit nurses go to the bedside to investigate patient related alarms: A descriptive qualitative study. Intensive Crit Care Nurs. 2017;43:101–7. https://doi.org/10.1016/j.iccn.2017.04.003.
20. Sowan AK, Tarriela AF, Gomez TM, et al. Nurses' perceptions and practices toward clinical alarms in a transplant cardiac intensive care unit: exploring key issues leading to alarm fatigue. JMIR Hum Factors. 2015;2(1):1–11. https://doi.org/10.2196/humanfactors.4196.
21. Movahedi A, Sadooghiasl A, Ahmadi F, et al. A grounded theory study of alarm fatigue among nurses in intensive care units. Aust Crit Care. 2023;36(6):980–8. https://doi.org/10.1016/j.aucc.2022.12.004.
22. Poncette AS, Spies C, Mosch L, et al. Clinical requirements of future patient monitoring in the intensive care unit: qualitative study. JMIR Med Inf. 2019;7(2):e13064. https://doi.org/10.2196/13064.
23. Vreman J, van Loon LM, van den Biggelaar W, et al. Contribution of alarm noise to average sound pressure levels in the ICU: an observational cross-sectional study. Intensive Crit Care Nurs. 2020;61:102901. https://doi.org/10.1016/j.iccn.2020.102901.
24. Najafi N, Robinson A, Pletcher MJ, et al. Effectiveness of an analytics-based intervention for reducing sleep interruption in hospitalized patients: A randomized clinical trial. JAMA Intern Med. 2022;182(2):172–7. https://doi.org/10.1001/jamainternmed.2021.7387.
25. Seifert M, Tola DH, Thompson J, et al. Effect of bundle set interventions on physiologic alarms and alarm fatigue in an intensive care unit: A quality improvement project. Intensive Crit Care Nurs. 2021;67:103098. https://doi.org/10.1016/j.iccn.2021.103098.
26. Bonafide CP, Localio AR, Holmes JH, et al. Video analysis of factors associated with response time to physiologic monitor alarms in a children's hospital. JAMA Pediatr. 2017;171(6):524–31. https://doi.org/10.1001/jamapediatrics.2016.5123.
27. Stacy J, Susan S. Managing alarms in acute care across the life span: electrocardiography and pulse oximetry. Crit Care Nurse. 2018;38(2):16–20. https://doi.org/10.4037/ccn2018468.
28. Cosper P, Zellinger M, Enebo A, et al. Improving clinical alarm management: guidance and strategies. Biomed Instrum Technol. 2017;51(2):109–15. https://doi.org/10.2345/0899-8205-51.2.109.
29. Gorisek R, Mayer C, Hicks WB, et al. An evidence-based initiative to reduce alarm fatigue in a burn intensive care unit. Crit Care Nurse. 2021;41(4):29–37. https://doi.org/10.4037/ccn2021166.
30. Balzer F, Agha-Mir-Salim L, Ziemert N, et al. Staff perspectives on the influence of patient characteristics on alarm management in the intensive care unit: A cross-sectional survey study. BMC Health Serv Res. 2023;23(1):1–15. https://doi.org/10.1186/s12913-023-09688-x.
31. Cho OM, Kim H, Lee YW, et al. Clinical alarms in intensive care units: perceived Obstacles of alarm management and alarm fatigue in nurses. Healthc Inf Res. 2016;22(1):46–53. https://doi.org/10.4258/hir.2016.22.1.46.
32. van Rossum MC, Vlaskamp LB, Posthuma LM, et al. Adaptive threshold-based alarm strategies for continuous vital signs monitoring. J Clin Monit Comput. 2022;36(2):407–17. https://doi.org/10.1007/s10877-021-00666-4.
33. Ruppel H, Pohl E, Rodriguez-Paras C, et al. Clinician perspectives on specifications for metrics to inform pediatric alarm management. Biomed Instrum Technol. 2023;57(1):18–25. https://doi.org/10.2345/0899-8205-57.1.18.
34. Pelter MM, Carey MG, Al-Zaiti S, et al. An annotated ventricular tachycardia (VT) alarm database: toward a uniform standard for optimizing automated VT identification in hospitalized patients. Ann Noninvasive Electrocardiol. 2023;28(4):e13054. https://doi.org/10.1111/anec.13054.
35. Zhou Y, Zhao G, Li J, et al. A contrastive learning approach for ICU false arrhythmia alarm reduction. Sci Rep. 2022;12(1):4689. https://doi.org/10.1038/s41598-022-07761-9.
36. Shanmugham M, Strawderman L, Babski-Reeves K, et al. Alarm-related workload in default and modified alarm settings and the relationship between alarm workload, alarm response rate, and care provider experience:

quantification and comparison study. JMIR Hum Factors. 2018;5(4):e11704. https://doi.org/10.2196/11704.
37. Dandoy CE, Davies SM, Flesch L, et al. A team-based approach to reducing cardiac monitor alarms. Pediatrics. 2014;134(6):1686–94. https://doi.org/10.1542/peds.2014-1162.
38. Sowan AK, Vera AG, Fonseca EI, et al. Nurse competence on physiologic monitors use: toward eliminating alarm fatigue in intensive care units. Open Med Inf J. 2017;11:1–11. https://doi.org/10.2174/1874431101711010001.
39. Li B, Yue L, Nie H, et al. The effect of intelligent management interventions in intensive care units to reduce false alarms: an integrative review. Int J Nurs Sci. 2024;11(1):133–42. https://doi.org/10.1016/j.ijnss.2023.12.008.
40. Ruppel H, Funk M, Clark JT, et al. Attitudes and practices related to clinical alarms: A follow-up survey. Am J Crit Care. 2018;27(2):114–23. https://doi.org/10.4037/ajcc2018185.

Publisher's note