Monitor Alarm Fatigue
An Integrative Review

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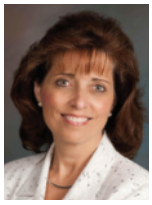
About the Author



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Abstract

Alarm fatigue is a national problem and the number one medical device technology hazard in 2012. The problem of alarm desensitization is multifaceted and related to a high false alarm rate, poor positive predictive value, lack of alarm standardization, and the number of alarming medical devices in hospitals today. This integrative review synthesizes research and non-research findings published between 1/1/2000 and 10/1/2011 using The Johns Hopkins Nursing Evidence-Based Practice model. Seventy-two articles were included. Research evidence was organized into five main themes: excessive alarms and effects on staff; nurse's response to alarms; alarm sounds and audibility; technology to reduce false alarms; and alarm notification systems. Non-research evidence was divided into two main themes: strategies to reduce alarm desensitization, and alarm priority and notification systems. Evidence-based practice recommendations and gaps in research are summarized.

Background

A cacophony of sound echoes through the modern hospital. Bells, beeps, chimes, and horns are all part of the noise-polluted environment that patients, families, and staff endure. They may be exposed to as many as 700 physiologic monitor alarms per patient per day.[1] The myriad of medical device alarms has created an environment that poses significant risk to patient safety. Device alarms are intended to alert clinicians of a hazardous condition and potential problems. However, when a caregiver is subjected to too many alarms, it disrupts his or her usual workflow and may result in errors due to omission, distraction, or inattention.

The ECRI Institute, a nonprofit organization that uses applied scientific research in healthcare to establish best practices for improving patient care, publishes an annual top ten technology hazards list. "Alarm hazards" is the number one health technology hazard for 2012.[2] Such hazards include inappropriate alarm modification, alarm fatigue, modifying alarms without restoring them to their original settings, and improperly relaying alarm signals to the appropriate person.[3] The problem of excessive alarms resulting in alarm fatigue has been reported in research literature for many years.[4-10] Studies have indicated that the presence of false and/or clinically insignificant alarms ranges from 80%–99%.[4-6]

Medical devices generate enough false alarms to cause a reduction in responding known as the cry wolf effect. Frequent alarms are distracting and interfere with clinicians performing critical tasks and may lead to staff disabling alarm systems.

Medical devices generate enough false alarms to cause a reduction in responding known as the cry wolf effect.[11] Frequent alarms are distracting and interfere with clinicians performing critical tasks and may lead to staff disabling alarm systems. Excessive false positive alarms result in caregiver apathy and desensitization such that real events are less likely to be acted upon.[12,13]

National attention to alarm hazards was spurred in 2010 by the death of a patient at Massachusetts General Hospital that was determined to be due to an alarm that had

inadvertently been turned off. The federal report indicated that nurses working among constantly beeping monitors contributed to the death of the patient.[14, 15]

This integrative review summarizes the current research and non-research evidence available regarding alarm fatigue.

Prevalence and Severity of Alarm Fatigue

Alarm fatigue, the lack of response due to excessive numbers of alarms resulting in sensory overload and desensitization, is a national problem.[2] From 2005 through 2008, the U.S. Food and Drug Administration (FDA) Manufacturer and User Facility Device Experience (MAUDE) database received 566 reports of patient deaths related to monitoring device alarms.[16] A four-month review of the MAUDE database between March 1, 2010 and June 30, 2010 revealed 73 alarm related deaths with 33 attributed to physiologic monitors.[17]

Physiologic monitor alarms are purposefully designed for high sensitivity to not miss a true monitor event. Cardiac monitors use single parameter thresholds that alarm when the set limit is violated. In a multisite study, Chambrin et al., determined the sensitivity and specificity of monitor alarms to be 97% and 58% respectively; positive predictive value was 27%; and negative predictive value was 99%.[6] In addition to high sensitivity, if monitor parameter thresholds are set too tight, true but clinically insignificant alarms may occur. These alarms are known as "nuisance" alarms. When the alarm is viewed as a "nuisance," the caregiver may disable, silence, or ignore the warning that is intended to make the environment safer. Rather than creating a safer environment, a large number of nuisance alarms have an opposite effect, resulting in desensitization.

Evidence-Based Practice Model And Search Strategy

The Johns Hopkins Nursing Evidence-Based Practice (JHNEBP) model[18] provided an organized approach to appraise, synthesize, and translate evidence for this review. The practice question asked was, "Does the amount of noise (false or nuisance alarms) as context to signal (true alarms) interfere with the nurse's response to physiologic monitor alarms?" Evidence strength and quality were assessed using the standardized scoring system found on the JHNEBP appraisal tools. According to this model, research evidence has the highest strength (level I, II, and III) and non-research evidence the lowest (level IV and V).[18]

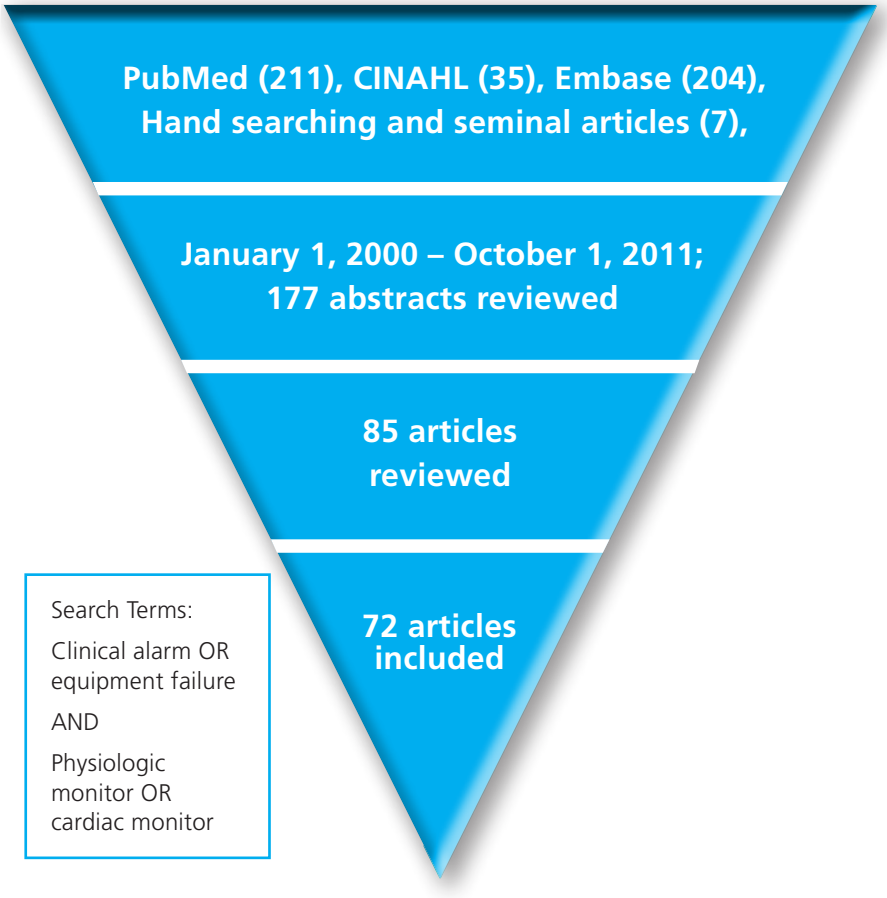

Figure 1. Search Strategy

When the alarm is viewed as a "nuisance," the caregiver may disable, silence, or ignore the warning that is intended to make the environment safer. Rather than creating a safer environment, a large number of nuisance alarms have an opposite effect, resulting in desensitization.

A comprehensive search of three databases (PubMed, Embase, and the Cumulative Index to Nursing and Allied Health Literature) was conducted. The search was limited to English with a publication date between 1/1/2000 to 10/1/2011 (Figure 1). One hundred seventy-seven abstracts were reviewed and 85 articles reviewed in entirety. Seventy-two articles were included in the individual evidence table (available upon request).

Research Findings Related to Alarm Fatigue

Research evidence was organized into five major themes:

1. Excessive alarms and effects on staff
2. Nurse's response to alarms
3. Alarm sounds and audibility
4. Technology to reduce false alarms
5. Alarm notification systems

Excessive Alarms and Effects on Staff

Excessive false alarms occur frequently and contribute to alarm desensitization, mistrust, and lack of caregiver response.[4-10] Many false positive alarms are induced and can be attributed to patient manipulation. Motion artifact contributes to excessive false alarms. Staff could avoid false alarms by suspending alarms for a short time period prior to patient manipulation.[5,6] Statistical methods may be suitable to decrease the number of false positive monitor alarms.[9]

Perceived alarm urgency contributes to the nurses' alarm response, but nurses use additional strategies to determine response including the criticality of the patient, signal duration, rarity of alarming device, and workload.

The Healthcare Technology Foundation (HTF) conducted a national online survey of clinicians, engineers, technical staff, and managers in 2006 regarding the effects of alarms. The majority of respondents agreed or strongly agreed that alarms activate too frequently, disrupt patient care, and reduce trust—causing caregivers to disable them.[19] Similar results were obtained when the survey was repeated in 2011.[20]

Nurses' Response to Alarms

Perceived alarm urgency contributes to the nurses' alarm response, but nurses use additional strategies to determine response including the criticality of the patient, signal duration, rarity of alarming device, and workload.[21-25] A caregiver's "probability match" is the alarm response based on the perceived true alarm rate. If an alarm system is perceived to be 90% reliable, the response rate will be about 90%; if the alarm system is perceived to be 10% reliable, the response rate will be about 10%.[21]

Nurses respond to alarms for different reasons, not just the fact that the alarm sounds. Nurses adjust the order of their activities by evaluating alarm urgency in relation to the patient's condition and have a greater tendency to react to alarms of longer duration and considered rare.[21,23,25] As workload or task complexity increases, alarm response and task performance deteriorates. Thus, signal duration is an important influence, but workload, patient condition, and task complexity may lead to other reaction strategies.[22,25]

Adjusting alarms to patient's actual needs ensures that alarms are valid and provides an early warning to potential critical situations. Documenting alarm parameters in the medical record was found to be an effective intervention for improving alarm adjustment compliance.[25]

Alarm Sounds and Audibility

Humans can discriminate about five to seven different categorical sounds.[27] There is controversy in the literature on the best type of audible alarm sound. IEC 60601-1-8 is an international standard addressing alarm function and sound.[28] IEC 60601-1-8 proposes simple melodic alarm sounds to distinguish eight alarm sources and priority codes these sounds as high, medium, or low priority. Some studies have recommended redesign of IEC 60601-1-8 melodic alarm sounds indicating that the sounds are difficult to identify and cannot be discriminated when there is task overlap. These studies have shown that nurses' learning of melodic sounds is poor and that nurses react quicker and more accurately to medium priority alarms despite indicating that high priority alarms sound more urgent.[29,30,31] Phonic abbreviation sounds, which are unintelligible to an untrained listener but recognizable to trained individuals, were studied as a potential type of alarm sound requiring further investigation.[32]

Audibility of infusion pump alarms was researched by Sobieraj et al.[33] In this study, the authors concluded that alarms were sufficiently audible and could compete with environmental noise when patient room doors were open. However, audibility was significantly reduced when room doors were closed or during environmental producing noise events such as floor buffing.[33] Thus, it is important to have adjunct alarm notification devices to ensure alarm audibility.

Alarms generate noise that may present occupational hazards or hinder patient recovery.[34, 35] Noise levels in most hospitals exceed the World Health Organization (WHO) recommen-

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To see tables that provide more detailed information about the JHNEBP Research and Non-Research Appraisal Tools, go to www.aami.org/publications/BIT

dations of 35 decibels (dB) during daytime hours and 30 dB for nighttime hours.[36] Noise levels have been consistently rising since 1960.[34, 35] Hirose et al., studied noise in 75 pieces of medical equipment. The dB level of 54% of the equipment studied had a fixed alarm sound and most equipment exceeded 70 dB. The authors concluded that alarm dB level should be adjusted according to the environmental noise level, and an automatic setting of alarm dB level should be set to maximum whenever the device is powered on.[37] This recommendation is in conflict with the findings from Ryherd et al. They recommended more research on the usefulness of visual and vibrating alarm systems, and concluded that noise contributes to staff stress symptoms including fatigue, concentration problems, and tension headaches.[35]

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Technology to Reduce False Alarms

There has been much research over the past 10 years with technology aimed at decreasing false positive alarms and increasing positive predictive value. Researchers have demonstrated that alarms often self-correct. Adding short delays can significantly decrease the number of ignored or ineffective alarms, which are often caused by suctioning, washing, repositioning, and oral care.[38]

Rather than using raw data, technology can base alarms on physiologic trends detected over a period of time. Signal filtering, algorithms, and/or artificial intelligence systems process alarms using filters or morphologic and timing differences to reduce the number of alarms.[39,40,64] "Smart alarms," which take into account multiple parameters, rate of change, and signal quality can reduce the number of false alarms. [10,41-45,64] Manufacturers of medical devices continue to work on smart alarm technology and alarm acquisition techniques to improve alarm accuracy.[12]

Alarm Notification Systems

Despite few studies to support the benefit of human monitor surveillance, this alarm management approach is prevalent in many hospitals. A Health Technology Foundation survey of 4,278 respondents indicated that central alarm management is viewed as advantageous, and many institutions (48%) use monitor watchers in their institution.[20] Monitor technicians did not show significant differences in mortality or frequency of transfer to critical care.[46] Zwieg et al., compared the use of a monitor technician versus a pager to alert nurses of arrhythmia events. Although false alarms were more frequent in the pager group, the amount of time it took to alert the nurse of an alarm event was less than one minute with both systems. Customization of alarm parameters decreased the false alarm rate thereby making a pager a viable option to arrhythmia notification.[47] Wireless technologies may be viable alternatives to human monitor surveillance. Comparative studies are needed to determine the best approach to promote positive patient outcomes.

Wireless technologies may be viable alternatives to human monitor surveillance. Comparative studies are needed to determine the best approach to promote positive patient outcomes.

Research Strengths and Limitations

There are a variety of observational research studies available on perception of alarms, alarm urgency response, and alarm fatigue. There are also a significant number of studies addressing the problem of alarm sensitivity. The quality of research studies was good to excellent.

There are few randomized controlled trials (RCTs) related to monitor alarm fatigue. The RCT studies available have small sample sizes and are conducted in laboratories with volunteers who may not have the same level of experience as trained healthcare professionals. Most evidence is observational or qualitative with few studies addressing patient outcomes. These studies are limited by known biases introduced by self-report, self-selection, manual data collection, and small sample size. Many of the studies are conducted in single sites resulting in bias and limiting extrapolation of results.

Non-Research Evidence Related to Alarm Fatigue

Non-research evidence supplements existing research findings as a mechanism for reducing alarm desensitization. Non-research evidence has been divided into two main themes which are summarized below.

Strategies to Reduce Alarm Desensitization

Clinical standards and expert opinion suggest many strategies to reduce alarm desensitization. The current mechanism for alarm generation is based on setting a monitor threshold limit. When an alarm limit is breached, an audible or visual signal is triggered. Currently, there are no standards for setting default alarm parameter thresholds or graduation of alarms related to degree of urgency.[48] Hospitals need to develop alarm setting and response protocols.[12,13,49,50] Technical alarms such as those on electrocardiograms (ECG) leads represent a large number of alarm occurrences. To reduce technical alarms, the ECRI Institute recommends proper skin preparation and replacing ECG leads and electrodes routinely.[13] A quality improvement project conducted on an adult medical progressive care unit and cardiology care unit demonstrated a 46% reduction in total alarms/pt/day after performing daily electrode change.[64]

If the alarm that is being generated is considered insignificant, then it should never be activated because the most that it can do is provide noise.

Hospitals should give considerable thought to alarms that should be activated, default limit parameter settings, and customizing alarms based on the patient's needs.[13] If the alarm that is being generated is considered insignificant, then it should never be activated because the most that it can do is provide noise. Using a quality improvement approach, Graham and Cvach[49] conducted small tests of change by altering monitor alarm parameters and limits to actionable levels on a 15-bed medical progressive care unit. During an 18-day period, the baseline number of high priority alarms (16,953) decreased by 43% (9,647 alarms) by eliminating duplicate alarms (for example, heart rate high OR tachycardia but not both) and by setting alarm limits to actionable levels as well as individualizing patient specific parameter limits.[49] Gross et al., found that alarm loads could be controlled with alarm limits set appropriately for the population. Simple limit adjustments from heart rate 120 to 130 bpm would have resulted in a 50% reduction of alarms.[43]

Alarm notification relies on a combination of technical devices and human factors. The notification system selected should complement the monitoring equipment, staffing model, alarm response protocol, and unit architectural layout.

To reduce alarms, the Healthcare Technology Foundation recommends initial and ongoing training on alarm-based medical devices that staff are expected to operate. Training should mimic the clinical environment where the device is used.[12] Clinical competency that reflects institutional policy assures care provider skill with physiologic monitoring.[48] Standardizing alarm sounds may also be an effective way to reduce the number of alarms that staff must learn.[50] Animated steps on how to troubleshoot alarms would also be helpful.[57]

Alarm Priority and Notification Systems

A key aspect of alarm management is assuring that care providers are aware of alarm conditions. Audible alarms are delineated as high, medium, and low priority. High-priority alarms indicate an urgent situation requiring immediate attention; medium-priority alarms indicate a dangerous situation requiring a quick response; and low-priority alarms indicate that attention is needed.[48] An alarm risk assessment, whereby alarms are assigned an alarm priority rating, may be useful when developing alarm policies and determining proper alarm response.[52]

Alarm notification relies on a combination of technical devices and human factors. The notification system selected should complement the monitoring equipment, staffing model, alarm response protocol, and unit architectural layout.[13] Basic alarm notification models include on-floor monitoring and remote monitoring. On-floor monitoring may be by direct notification to the care provider or filtered by a unit-based human monitor watch who notifies the assigned caregiver. Remote monitoring involves delivering alarm signals to a location outside of the care unit.[13]

Alarm enhancement technology provides additional means to deliver alarm signals from monitors to caregivers. These technologies include auxiliary displays such as marquee signs and waveform screens.[52] The purpose of these displays is to provide additional locations to view alarms on units with long hallways or dispersed geography.[13] Issues of patient confidentiality have arisen with these devices;

however, they can be configured without displaying patient names to protect privacy.

Integrated middleware systems link alarm systems with wireless devices. These systems route alarms to caregivers and may employ delays and alarm escalation.[54] Use of alarm notification systems that provide context to the care provider and closed-loop communication is recommended.[55,56]

Organizations committed to finding solutions have formed interdisciplinary alarm management committees to conduct an alarm risk assessment and explore strategies for alarm reduction.[57] An alarm management policy is essential to define alarm accountability. Alarm data informs proper settings for unit default parameter limits, assists in determining alarm prioritization, and reduces alarm fatigue. Each unit must be analyzed to determine the proper alarm management strategy. It is difficult to apply a "one-size-fits-all" approach to alarm management for all types of monitored units. Initial and ongoing training on alarming devices is recommended.[58,59,60]

Gaps in Knowledge, Need for Further Research

There are several areas where more research is indicated. The best type of audible alarm is controversial and needs further investigation. There are no studies on the proper settings for alarm default parameter thresholds. Research is needed on the best way to set monitor limits and levels to improve alarm positive predictive value while not substantially reducing sensitivity. More research is needed on false alarm suppression algorithms. A gap in knowledge exists on the risk/benefit of alarm standardization across like medical devices. Research is needed on whether alarm standardization will improve staff's ability to distinguish device alarms, thereby improving alarm responsiveness. Finally, research is needed on alternate approaches to audible alarm notification as well as effectiveness of wireless technology for alarm notification as compared to human monitor watch.

Evidence-based Practice Recommendations

To decrease monitor alarm fatigue, the following strategies are recommended:

1. **Technology**
   a. Smart alarms, which take into account multiple parameters, rate of change and signal quality, can reduce the number of false alarms.[10,41-45,64]
   b. Alarm technology that incorporates short delays can decrease the number of ignored or ineffective alarms caused by patient manipulation.[38]
   c. Standardizing alarm sounds may be an effective way to reduce the number of alarms that staff must learn.[50]
   d. Animated steps on the monitoring equipment for troubleshooting alarms would be helpful in assuring best practice with equipment.[57]
2. **Hospital**
   a. Hospitals should engage an interdisciplinary alarm management committee to conduct an alarm risk assessment and explore strategies for alarm reduction.[57]
   b. Hospitals should develop alarm setting and response protocols.[12,13,49,50]
   c. Activated alarms should be set to actionable limits and levels.[43,49]
   d. Staffing model should consider that alarm response time is a function of primary task workload; as workload increases, time to alarm response increases, and alarm task performance gets worse.[22]
   e. Alarm enhancement technology provides additional means to deliver alarm signals from monitors to caregivers.[52] These technologies may include pagers, phones, and auxiliary displays such as waveform screens.[13] Use of alarm notification systems that provide context to the care provider and closed-loop communication is recommended.[55,56]
   f. Investment in initial and ongoing training on alarming devices.[58,59,60] Clinical competency that reflects institutional policy assures care provider skill with physiologic monitoring.[48] Training should mimic the clinical environment where the device is used.[12]
   g. To reduce patient and staff stress symptoms, noise reduction strategies should be employed.[35,36]
3. **Caregiver**
   a. Staff could avoid false alarms by suspending alarms for a short time period prior to patient manipulation.[5,6]
   b. Adjustment of alarms to patients' actual needs ensures that alarms are valid and provides an early warning to potential critical situations.[47,49]
   c. Proper skin preparation and replacing ECG leads and electrodes routinely decreases false alarms.[13,60,64]
   d. Documentation of alarm parameters in the medical record is an effective intervention for improving alarm adjustment compliance.[25]

Summary

Serious harm and death have occurred from missed alarm events. This integrative review demonstrates the research and non-research findings from the past decade related to monitor alarm fatigue. Gaps in knowledge and need for further research was discussed. Outcomes research, which generates the highest level of evidence, is needed with a focus on patient outcomes rather than just on reduction of the number of alarms. ■

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