Alarm Fatigue
A Patient Safety Concern

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ABSTRACT

Research has demonstrated that 72% to 99% of clinical alarms are false. The high number of false alarms has led to alarm fatigue. Alarm fatigue is sensory overload when clinicians are exposed to an excessive number of alarms, which can result in desensitization to alarms and missed alarms. Patient deaths have been attributed to alarm fatigue. Patient safety and regulatory agencies have focused on the issue of alarm fatigue, and it is a 2014 Joint Commission National Patient Safety Goal. Quality improvement projects have demonstrated that strategies such as daily electrocardiogram electrode changes, proper skin preparation, education, and customization of alarm parameters have been able to decrease the number of false alarms. These and other strategies need to be tested in rigorous clinical trials to determine whether they reduce alarm burden without compromising patient safety.

Keywords: alarm fatigue, patient safety, regulatory agencies

One needs only to step into any busy hospital unit to hear a cacophony of alarm sounds. Alarms are found on most medical devices used at the bedside. These alarms sound every hour of every day. An analysis of alarms at The John Hopkins Hospital, Baltimore, Maryland, revealed a total of more than 59,000 alarm conditions over a 12-day period—or 350 alarms per patient per day.1,2

The purpose of clinical alarms is to enhance safety by alerting clinicians to deviations from a predetermined normal status. The alarms alert clinicians when a patient’s condition is deteriorating and when a device is not functioning as it should. Device or system problems include loose connections or an intravenous medication having run out. Although nothing may be wrong with the patient, these conditions must be corrected immediately. In a well-publicized case,1 no one responded to a monitor alarm that sounded softly for about 75 minutes, signaling that the patient’s telemetry battery needed to be replaced. The battery eventually died, and when the patient went into cardiac arrest, no loud crisis alarm sounded. The patient was found unresponsive and could not be resuscitated.

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A perfect alarm system would never miss a clinically important event—the sensitivity would be 100%. Also, the alarm would not go off when there is no clinically important event—the specificity would be 100%. By design, alarms are highly sensitive so that they do not miss an important event. However, this high sensitivity is achieved at the expense of specificity. False alarms are very common, which can lead to alarm fatigue.

Alarm fatigue occurs when nurses become overwhelmed by the sheer number of alarm signals, which can result in alarm desensitization and, in turn, can lead to missed alarms or a delayed response to alarms. The desensitization to alarms occurs largely because the devices have “cried wolf” too often—as the boy in Aesop’s fable did. Studies have shown that in some hospital units, more than 85% of alarms are false.4–7 The large number of false alarms has caused nurses to turn down the volume of audible alarm signals, adjust the alarm settings outside limits that are safe and appropriate for the patient, ignore alarm signals, or even deactivate alarms, which has resulted in sentinel events and patient deaths.

Alarm fatigue is recognized as an increasingly critical safety issue in current clinical practice. The Healthcare Technology Foundation, an organization promoting the development, application, and support of safe and effective health care technologies, initiated a clinical alarms improvement program in 2004. The Healthcare Technology Foundation has conducted 2 large national surveys on alarm signals.1,8 The ECRI Institute, an independent nonprofit organization that addresses patient safety, named alarm hazards as number 1 of the “Top 10 Health Technology Hazards” for both 2012 and 2013.9 Recently, The Joint Commission released a Sentinel Event Alert,10 addressing medical device alarm safety in hospitals. The Sentinel Event Alert warned that alarm fatigue can jeopardize patients, and urged hospitals “to take a focused look at this serious patient safety issue.”

In recent years, the number of devices with alarms at the bedside has grown exponentially. Alarms from monitors, ventilators, infusion pumps, feeding pumps, pulse oximeters, intra-aortic balloon pumps, sequential compression devices, beds, and many other devices beep endlessly, demanding our attention. In a study in a medical intensive care unit, Görges et al.6 found that ventilators (46%) were the source of the highest proportion of alarms, followed by monitors (37%). In most other settings, physiological monitors produce the most alarm signals. In this article, we focus on physiological monitors, which include hard-wire monitors in critical care areas, telemetry monitors, and pulse oximeters.

Patient Safety

Scope of Problem

In 1974, the ECRI Institute published its first report of a sentinel event related to an alarm. An ignored alarm signal on a hypothermia machine resulted in serious patient burns.11,12 The report identified that a minor drawback to the hypothermia machine was the alarm light that would flash continuously until the patient’s temperature reached the desired value. Because of the constant flashing of the alarm light during a normal phase of the warming process, the alarm could be ignored during a critical event.

By 1982, researchers recognized the increasing number of monitoring signals, with “no end in sight.”13 A year later, Kerr and Hayes14 identified that each patient could have 6 or more alarms that could increase the risk of caregiver confusion as to which alarm is going off and would actually be contrary to the patient’s best interest. Cropp et al.17 examined whether physicians, nurses, or respiratory therapists could differentiate alarm signals heard in an intensive care unit and found that of the 33 different sounds, they correctly identified only 50% of the critical alarm signals and 40% of the noncritical alarm signals. By 1999, 40 different alarms for the ventilator, electrocardiogram (ECG), arterial pressure, and pulse oximetry were identified.18

Studies have demonstrated that most alarm signals have no clinical relevance. The percentage of false alarms ranges from 72% to 99.4%,4,6,7,12,18 which creates a “cry wolf” situation in which staff will respond to the alarm the percentage of time they deem it reliable.18–21 The dire consequences of this situation are seen in patient deaths being attributed to alarm fatigue. National attention was brought to this issue of alarm fatigue after the death of a patient in a Massachusetts hospital. When the alarm on the heart monitor was inadvertently left off, nurses and physicians had a delayed response to providing emergency care (http://bit.ly/c2cGF6).1,22 Three patient deaths from 277 reports related to alarm response caused
the state of Pennsylvania to conduct a failure mode and effects analysis to help prevent further occurrences. In a patient undergoing abdominal surgery, the alarms were turned off for an intraoperative radiograph and never turned back on, causing respiratory distress to go unnoticed and resulting in death 11 days later. More recent was the tragic death of a 17-year-old who had respiratory decompensation after a tonsillectomy, and because the monitoring system was muted, her distress was missed by the nurses.

Alarm-related events are underreported. Some estimates put the actual number of alarm-related deaths 10-fold or higher than what the data show. Clearly, the reporting of alarm-related events is increasing. As awareness of the issue increases, recognition and reporting will increase. The reporting of alarm-related events is critical to not only identify the magnitude of the problem but also determine strategies and/or interventions to eliminate it.

The Joint Commission

In 2003, The Joint Commission set a National Patient Safety Goal to improve the overall effectiveness of clinical alarms, which was in response to a review of 23 incidents of death or injury related to ventilators in which the root cause analysis revealed that contributing factors included (1) alarm off or set incorrectly (22%), (2) no alarms for certain disconnects (22%), and (3) alarm not audible in all areas (22%). After 2004, the effectiveness of alarms was removed as a National Patient Safety Goal and became one of The Joint Commission’s accreditation requirements. The value of The Joint Commission’s identification of alarm fatigue as a patient safety issue can be demonstrated in a survey of hospitals’ chief executive officers and senior quality executives that revealed that 87% of respondents said that government and regulatory agencies exerted a high level of influence over institutional quality priorities.

In April 2013, The Joint Commission published a Sentinel Event Alert on medical device alarm safety in hospitals. The alert cited the 2010 case of a 60-year-old patient in Massachusetts who had died not because of the condition that originally brought him to the hospital but from the delayed response to an alarm. The alert identified the absence of or inadequacy of an alarm system, improper alarm settings, inaudibility of alarm signals, and alarms being turned off as contributing factors to deaths. Also cited was alarm fatigue. The most common contributing factors, along with alarm settings not being customized to the patient, were inadequate staff education and inadequate staffing to respond to alarms.

Recommendations and potential strategies for improvement included leadership ensuring a process for safe alarm management, inventory of alarm-equipped medical devices, guidelines for alarm settings and tailoring of alarms, maintenance of alarm-equipped devices, training and education for the clinical care team, and leadership and organizational planning.

Recognizing that patients can be compromised if clinical alarm signals are not properly managed, The Joint Commission released its 2014 National Patient Safety Goal on Alarm Management in June 2013. By July 1, 2014, leaders need to establish alarm system safety as a hospital priority and identify the most important alarms to manage. In addition, by January 1, 2016, hospitals will be expected to develop and implement policies and procedures for managing alarms and to educate staff about the purpose and proper operation of alarms systems for which they are responsible.

ECRI Institute

The ECRI Institute is an independent, non-profit organization that examines the best approaches to improving the safety, quality, and cost-effectiveness of patient care. Every year, the ECRI Institute identifies the “Top 10 Health Technology Hazards,” which focuses on those technologies that need special attention in the coming year. Selections are based on potential for harm, frequency, breadth, insidiousness, and profile by a group of engineers, scientists, and patient safety analysts from the ECRI Institute. The final decision on the top hazard is based on health care- and technology-related problem reports, a critical review of the literature, and conversations with persons from practice including clinicians, engineers, administrators, and manufacturers who supply the devices. For both 2012 and 2013, alarm fatigue was the number 1 identified hazard. The ECRI Institute’s recommendations in approaching this issue included examinations of the organization as a whole about alarms, in addition to more targeted assessments. The ECRI Institute also recommended an evaluation of the manner in which
alarms are handled by devices and systems, the overall alarm load, the number of parameters being monitored, staffing levels and patterns, the physical layout of the unit, and protocols and policies for alarm system management. The ECRI Institute also stressed the importance of soliciting input from clinical staff, especially nurses.

Healthcare Technology Foundation
“The American College of Clinical Engineers formed the Healthcare Technology Foundation on the principle that achieving improvement in the safe use of healthcare technology requires diverse stakeholders to come together in order to utilize their collective knowledge on the design, use, integration, and servicing of healthcare technology, systems, and devices” (http://www.thehtf.org/). One of their first initiatives was an effort to improve the effectiveness of clinical alarms. Included in their assessment of alarms were forums and meetings. A culmination of the work was the development of a survey of more than 1300 clinicians, engineers, technical staff, and managers on the topic. The survey revealed that effective alarm management relied on equipment design that promoted appropriate use, clinicians taking an active role in learning how to use the equipment, and hospitals devoting the necessary resources to develop effective management schemes. The Healthcare Technology Foundation’s final recommendations were 3-fold: (1) the medical device industry should design alarm systems that are operationally intuitive; (2) health care organizations need to recognize the limitations of alarm systems and use them only as a tool in the overall assessment; and (3) education for clinicians is a critical aspect of the management of the monitoring and needs to start during the purchasing process. The survey was repeated in 2011 with 4278 responders, with publications in submission.1

Association for the Advancement of Medical Instrumentation (AAMI)
The AAMI is a nonprofit organization with the mission of supporting the health care community in the development, management, and use of safe and effective medical technology. Recognizing that “medical alarm systems are out of control,” an interprofessional summit was convened in collaboration with the Food and Drug Administration, The Joint Commission, the American College of Clinical Engineers, and the ECRI Institute to address the challenging issue of alarm system safety.2 The resulting document, Clinical Alarms: 2011 Summit, contained the 7 identified clarion themes. Within each theme, challenges, priority actions, and accountability were identified. Reflecting its interprofessional approach, accountable parties included manufacturers, researchers, responsible organizations, standards-setting organizations, regulatory and patient safety organizations, nursing organizations, and clinicians. A “Top 10 Actions You Can Take Now” was developed, with gaining interprofessional leadership support being number 1. Other steps identified included interprofessional teams that would address alarm fatigue across all environments of care, continuous improvement processes, optimization of alarm limits and delays, alarm system configuration policy based on evidence, changing single-use sensors more frequently to reduce nuisance alarm conditions, education for all clinical operators, and sharing experiences with AAMI, the Food and Drug Administration, The Joint Commission, and the ECRI Institute. Also recognized was the opportunity to learn from other industries where safety is intensely important, such as the nuclear power industry.

American Association of Critical-Care Nurses
The issue of alarm fatigue is a priority of the American Association of Critical-Care Nurses. At the 2013 National Teaching Institute, alarm fatigue was 1 of 4 topics at the Patient Safety Summit, and the 2013 National Teaching Institute ActionPak was focused on this topic. An ActionPak is an online toolbox of evidence-based nursing resources that the American Association of Critical-Care Nurses produces annually in conjunction with National Teaching Institute. In addition, a Practice Alert on alarm management and a webinar devoted to the topic were a part of the approach in addressing the issue. Included in the recommendations of how to address alarm fatigue were proper skin preparation for ECG electrodes, changing ECG electrodes daily, customizing alarm parameters and levels on ECG monitors (eg, life-threatening vs advisory alarms), customizing delay and threshold settings on oxygen saturation (SpO₂) monitors, initial and ongoing education, and monitoring only those patients with clinical indications for monitoring.
Summary
Common themes in addressing the issue of alarm fatigue include education, customization and/or optimization of alarms, and addressing the issue from a systems perspective (see Table 1). Adequate staffing also has been identified in managing patient alarms. However, Bitan and colleagues state that if a nurse responded to each alarm, “...it would be almost impossible to perform any activity that requires more than a few seconds.” Although adequate nurse staffing is clearly a need, just addressing the staffing issue without identifying the underlying causes of alarm fatigue does not solve the problem.

Interventions to Reduce Alarm Fatigue
Although the problem of alarm fatigue has been well-documented in the literature, intervention studies to guide clinicians in an effort to reduce and/or eliminate false and nonactionable alarms are lacking. In this section, we review the evidence related to alarm fatigue and recommend interventions in areas in which the evidence is sufficiently strong.

ECG Electrodes
A relationship between electrode-skin contact and electrical impedance measurement on signal quality has been identified. Indeed, much of the resistance with artifact is caused by dead skin cells; proper skin preparation before electrode placement can reduce artifact by lowering skin impedance. In 2 separate studies, mild abrasion with fine sandpaper was demonstrated to decrease skin resistance and to minimize artifact.

Recognizing the relationship between electrode-skin contact and electrical impedance on signal quality, Cvach and colleagues conducted a quality improvement project in which ECG electrodes were changed every day on patients in 2 adult acute care units. They demonstrated a 46% reduction in the average number of alarms per bed per day.

Individualizing Alarm Parameters
The AAMI’s 2011 Summit on Clinical Alarms recommended that alarm system configuration policy should be based on clinical evidence as opposed to accepting default alarm configurations. However, minimal research has been conducted on appropriate alarm parameters, and no studies could be found from a critical care setting. The lack of research on ECG monitoring was recognized by Drew et al, who developed ECG monitoring guidelines on the basis of expert opinion, because there was little research on which to make recommendations. Indeed,

Table 1: Resources for Alarm Safety

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<tr>
<th>Organization</th>
<th>Web Site</th>
<th>Specific Resources</th>
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<td>The Joint Commission</td>
<td><a href="http://www.jointcommission.org">http://www.jointcommission.org</a></td>
<td>Sentinel Event Alert&quot; (<a href="http://www.jointcommission.org/sea_issue_50/">http://www.jointcommission.org/sea_issue_50/</a>)</td>
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<td>ECRI Institute</td>
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this lack of evidence has been cited as a patient safety issue in configuring alarm settings. In addition, as alarm limits become more sensitive and less specific, more false alarms are generated. By relying on expert opinion and/or quality improvement studies, the core intervention that influences the outcome may be hard to distinguish from efforts to implement it.

An attempt to identify appropriate alarm settings and individualizing alarms has been one approach to minimizing nuisance alarms. Burgess examined a data set of continuous heart rate and respiratory rate data from a general ward population and found a high heart rate limit of 130 to 135/min, a low heart rate limit of 40 to 45/min, a high respiratory rate limit of 30 to 35/min, and a low respiratory rate limit of 7 to 8/min optimized false alarm rates. Graham and Cvach studied the impact of nurse education and revising default settings for the unit’s monitor alarms, including parameter limits and levels. In this quality improvement project, they demonstrated a 43% reduction in critical monitor alarms. As default limits are widened, we need to ensure that critical events are not missed and patients are not harmed.

In addition to individualizing the alarms that are set, an understanding of potentially overlapping or redundant alarms helps identify possible opportunities for change. An assessment of the necessity of all the alarms should be conducted. For example, many systems have both a tachycardia and a high heart rate alarm that are configured slightly differently but provide clinicians with essentially the same information from 2 different alarms. Thus, audible alarms may not be required for both, and a visual alarm may be appropriate. Some systems have an alarm signal for a staff alert that is available on a telemetry box but may not be needed, as the assist button in the patient’s room or communication for assistance is via wireless communication systems.

Individualizing alarms also includes examining $\text{SpO}_2$ parameters. Welch demonstrated that increasing alarm delays in $\text{SpO}_2$ monitors from 5 to 15 seconds decreased alarms by 70%. In addition, by decreasing alarm thresholds from 90% to 88%, alarms decreased by 45%. However, clinicians will need to work with the medical device industry to address this issue. Currently, manufacturers primarily establish alarm settings. For example, at one of the author’s (S.S.) hospitals, the $\text{SpO}_2$ delay setting was at 4 seconds, and the hospital personnel are unable to change the parameter.

### Interprofessional Teams

When Boston Medical Center began to address the problem of alarm fatigue, they formed an interprofessional team that was headed by the chief medical officer. Indeed, including senior management in addressing the issue of alarm fatigue is crucial. The role of senior leadership and their commitment to patient safety have been demonstrated to be critical in health care organizations. Better quality outcomes have been associated with hospital boards of directors who spend 25% of their time on quality issues and receive a formal quality performance measurement report. In turn, leaders must recognize that the system needs to change, not the employees.

The problem of alarm fatigue also includes opportunities for partnerships that include the medical device industry. The industry needs to broaden its role in solving the problem. Indeed, the industry should be brought in to be a part of the alarm management work group, so that all parties understand the complexity of the work and what is needed to promote patient safety by designing safer systems.

### Human Factors

Human factors engineering focuses on the design of tools, machines, and systems while taking into account human capabilities, limitations, and characteristics, with the goal of safe human use. The importance of human factors in the development of alarm systems and their potential to help provide a solution has been identified. Alarm systems have been shown to be configured incorrectly, reflexively inactivated, and overridden, misinterpreted, and simply not heard. In the development of alarm systems, engineers should follow health care providers in the clinical setting to understand how we work. In addition, usability testing in health care settings is rarely done.

### Measurement

Unless we are able to measure the outcome, we are unable to fix the problem. Feedback is important, as it helps maintain momentum and build trust in management’s ability to solve patient safety problems. Measurement is critical to understanding the scope of the problem and to assessing whether interventions are leading to improvements. However,
measurement is very complex. The Johns Hopkins Hospital took 2 years to determine how to access and measure the data on the number and type of alarms. Involvement of the information technology department and biomedical engineering is essential, as they need to identify how to examine data from the monitor.

Future Work
What do we still not know related to improving the safety related to alarms? The fundamental unanswered question is: What is the best way to increase specificity of alarms without a significant loss of sensitivity? Although work has begun, interventions to reduce false or nonactionable alarms still have not been rigorously tested.

The focus of future clinical research related to alarms on monitors can be classified into 4 areas: (1) false alarms, (2) nonactionable alarms, (3) appropriateness of monitoring, and (4) processes of care. We propose possible topics for research in each of these areas. They all need to be tested in rigorously designed studies. Alarm fatigue occurs when nurses are barraged by so many false or nonactionable alarms that they become desensitized. False alarms occur when no valid triggering event occurs, whereas nonactionable alarms correctly sound but for an event that has no clinical relevance. These 2 types of nuisance alarm signals should be distinguished, because possible approaches to reducing their occurrence differ.

False Alarms
Possible ways to reduce false alarm signals from cardiac monitors need to be studied. First, a protocol to ensure good signal quality from ECG electrodes needs to be tested. The protocol should include good preparation of the skin to ensure that electrodes adhere well, which will help prevent electrodes from becoming loose and falling off and help avoid artifact that could mimic a tachycardia and set off an alarm. The protocol also may include changing electrodes daily. Second, a protocol that promotes context awareness, such as temporarily silencing alarms when doing patient care, should be evaluated. Third, the use of “smart” alarms that consider other parameters before sounding, such as considering blood pressure before alarming for asystole, needs to be tested. By incorporating information from other parameters, a smart alarm system can determine a more robust hypothesis of an alarm’s cause and suppress false alarms.

Nonactionable Alarms
Possible ways to reduce nonactionable alarms also need to be studied. As discussed earlier, changing default settings for the particular patient population and customizing alarm settings to the individual patient have been tried. Quality improvement initiatives have demonstrated reductions in the number of alarm signals, with no apparent harm to patients. However, these interventions have not been tested in rigorously designed clinical trials to determine whether they can be implemented without compromising patient safety. We also need to evaluate the safety of deactivating default alarms for conditions we no longer treat, such as premature ventricular contractions (PVCs). Premature ventricular contractions have not been treated for more than 20 years, since the Cardiac Arrhythmia Suppression Trial was stopped for excess mortality rate related to the use of antiarrhythmics for asymptomatic ventricular arrhythmias. However, PVC alarms are rarely deactivated. One of the primary causes of nonactionable alarms is an outdated algorithm for PVCs that does not reflect current evidence-based practice. However, PVCs in patients at risk for torsades de pointe should be monitored, because PVCs are known precursors for torsades de pointe.

Appropriateness of Monitoring
Additional research related to indications for monitoring is needed. Perhaps the most effective way to reduce both false and nonactionable alarms is to avoid unnecessary monitoring and discontinue monitoring when it is no longer clinically indicated. The more patients who are being monitored, the more alarm signals will sound. The availability of sophisticated monitors does not mean we should use them for all patients. The American Heart Association Practice Standards for ECG Monitoring specify who should be monitored and for how long. Litigation-wary physicians may order cardiac monitoring for patients who have no clinical indication for it. In an era of inadequate staffing, alarms from monitors may substitute for direct human surveillance. Because monitoring is noninvasive, it seems harmless. However, unintended consequences occur, such as deaths related to alarm fatigue.
Processes of Care
Future research also should address processes of care related to alarm signals. Various approaches to alarm notification need to be evaluated, including the effectiveness of wireless technology, such as phones and pagers, split bedside monitor screens in critical care areas, and hallway waveform screens. The use of central monitoring with monitor watchers was not associated with lower rates of most adverse outcomes, including death and transfer to a critical care unit.\(^{49,50}\)

The use of monitor watchers needs to be compared with other alarm notification modalities. Also, we do not know how many patients a monitor watcher can effectively watch, or the best location (eg, on unit vs in a remote location). A cost-benefit analysis needs to be done to determine whether better patient outcomes justify the increased cost of monitor watchers. Last, will the use of monitor watchers result in a reduction in nurses’ knowledge of ECGs and ECG monitoring? We need to determine the most effective way to educate clinicians about the full capability of the devices they are using.

Study Design
Consideration of the study design of future research is critical. Randomized controlled trials, which generate the highest level of evidence, are needed. Studies must be interdisciplinary, specifically with collaboration among the medical device industry, biomedical engineers, and clinicians. In addition, biostatisticians and academic researchers should be included. Multisite studies are essential, and the studies must have meaningful outcomes. The focus needs to be on patient outcomes rather than only on reduction of the number of alarm signals. Statistical power may be lacking for mortality and sentinel events. We need large multicenter studies and/or appropriate surrogates for outcomes. Potential funders of such research (eg, the National Institutes of Health, foundations, industry) must make testing of alarm management strategies a funding priority.

Conclusion
Ironically, the very alarm systems that were created to enhance patient safety have themselves become an urgent patient safety concern. We need to fix our alarm systems to achieve the highest levels of both sensitivity and specificity. The goal is to eliminate alarm fatigue and provide a safer health care environment.

REFERENCES


