13. Alarm Fatigue

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Introduction

Alarm fatigue occurs when clinicians experience high exposure to medical device alarms, causing alarm desensitization and leading to missed alarms or delayed response. As the frequency of alarms used in healthcare rises, alarm fatigue has been increasingly recognized as an important patient safety issue. Although the problem of alarm fatigue has been well documented, alarm-related events are often underreported, and there is still limited research examining interventions to address the issue.[1] In this chapter, we discuss two system-level patient safety practices (PSPs) that aim to address alarm fatigue: safety culture and risk assessment.

Addressing alarm fatigue through improving safety culture involves system-wide interventions, such as leadership ensuring that there are clear processes in place for safe alarm management and establishing practices to share information about alarm-related incidents and prevention strategies. The studies included in this summary provide moderate evidence for reduction in total alarms and noise level following the implementation of features of safety culture. Surveys assessing nurses' perceptions of alarm fatigue and behavior changes regarding alarm management showed mixed results; however, two studies reported perceived reduction in alarm fatigue. More high-quality studies are needed to test the effects of safety culture elements on process and outcome measures related to alarm fatigue.

Performing baseline alarm risk assessments is an important step in order to understand current needs and conditions contributing to alarm fatigue. Conducting an alarm risk assessment can include evaluating medical devices and computer systems, analyzing data from clinical event reporting systems, and assessing patient satisfaction and the physical environment. There is currently limited research studying the impact of conducting alarm risk assessments on reducing alarm fatigue. The studies in this review examined alarm risk assessments as a component of larger quality improvement (QI) projects or system-wide initiatives; still, they provide moderately strong evidence supporting the use of multidisciplinary teams to conduct these assessments.

Background

Healthcare continues to become increasingly computerized, and clinicians use an assortment of equipment and technology to monitor patient conditions. Most healthcare devices provide auditory or visual warnings intended to alert clinicians when a patient's condition deviates from a predetermined normal range. Many device alarms emit different sounds, tones, and/or pitches depending on the level of severity (i.e., advisory vs. warning vs. crisis alarms) to help clinicians determine how to respond. System status or non-clinical alarms can also occur and are caused by mechanical or electrical problems, such as a device needing new batteries.[2] Device alarms can be an important tool to assist in clinical decision making; however, alarms can become hazardous to patient safety if excessive alarm frequency coupled with high prevalence of false alarms leads to alarm fatigue.

Alarm fatigue occurs when clinicians, especially nurses, become desensitized to safety alarms due to the sheer number of alarm signals,[3] which in turn can lead to missed alarms or delayed response.[1] Alarm desensitization is compounded by the fact that false or nonactionable alarms occur frequently. False

alarms are those that occur in the absence of an intended valid event,[4] and nonactionable alarms occur when an alarm system works as designed but signifies an event that is not clinically significant and/or requires no additional intervention.[5] The high volume of these nuisance alarms is not only disruptive, but also creates a situation where staff doubt the reliability of alarms and as a result turn down the volume, ignore, or deactivate the alarms.[5] This adversely affects patient safety because clinicians are not only ignoring the nuisance alarms, but also ignoring or missing many clinically significant and actionable alarms.[3]

Importance of Harm Area

Alarm fatigue is increasingly recognized as a critical safety issue, and alarm management has become a priority for improvement in hospitals. From 2005 to 2008, the U.S. Food and Drug Administration (FDA) Manufacturer and User Facility Device Experience (MAUDE) reporting system received 566 reports of patient deaths related to monitoring device alarms.[6] Alarm fatigue was a major contributor to these events due to the excessive number of alarms and high percentage of false alarms.[6] A study at a major academic medical center found a total of more than 59,000 alarms over a 12-day period,[1] while another study found 16,953 total alarms over an 18-day period on a single medical unit.[7] Studies have shown that the percentage of false alarms can range from 72 percent to 99 percent.[1]

In growing awareness of this issue, a number of national organizations have established alarm management guidelines and prioritize addressing alarm fatigue. Since initiating its annual list of top 10 health technology hazards in 2011, the ECRI Institute has consistently identified alarm hazards as a top issue.[8] In 2011, the Association for the Advancement of Medical Instrumentation (AAMI) convened a summit with FDA, the Joint Commission, the American College of Clinical Engineers, and the ECRI Institute to address the issue of alarm safety, and published a report outlining recommendations, challenges, and priority actions.[9] In 2013, the Joint Commission published a Sentinel Event Alert on medical device alarm safety, which identified alarm fatigue as a main contributing factor to patient deaths.[1] Later that year, the Joint Commission released its 2014 National Patient Safety Goal on Alarm Management in two phases of implementation. Beginning in 2014, hospitals were required to establish alarms as an organization-wide priority and identify the most important alarms to manage based on their own internal situations. Beginning in 2016, hospitals were expected to establish policies for managing alarms and educate staff about alarm management.[10]

Methods for Selecting PSPs

Initial literature searches for PSPs in the alarm fatigue harm area were conducted, focusing on systematic reviews and guidelines. Results of these searches were reviewed by harm-area task leads to identify PSPs, iterate on searches as needed, and refine lists of potential alarm fatigue PSPs on which to focus for the report. Then the project Technical Expert Panel and Advisory Group were engaged via a survey to prioritize PSPs for inclusion in the report. These survey results, along with refined recommendations for PSP inclusion, were submitted to the Agency for Healthcare Research and Quality (AHRQ) for review. After several rounds of review with AHRQ, two alarm fatigue PSPs were selected.

What's New/Different Since the Last Report?

The potential for harm due to alarms' high frequency and low specificity was briefly discussed in the report Making Health Care Safer I, and alarm fatigue was mentioned in Making Health Care Safer II in respect to computerized provider order entry with clinical decision support systems. This is the first

Making Health Care Safer report to include an evidence review of alarm fatigue as a harm area and look at interventions specifically related to addressing alarm fatigue.

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13.1 Patient Safety Practice 1: Safety Culture

13.1.1 Practice Description

Establishing a culture of safety is essential to improving overall healthcare quality. Broadly, key features of safety culture include: acknowledgment of the high-risk nature of an organization's activities; a blame-free environment where individuals are able to report errors without fear of punishment; encouragement of collaboration across staff levels and disciplines to seek solutions to patient safety problems; and an organizational commitment of resources to address safety concerns.[1] Addressing alarm fatigue through improving safety culture can involve a variety of interventions that are often implemented as a system-wide or unit-wide initiative. Examples of these elements include the following: leadership ensures there are clear processes in place for safe alarm management and response; leadership establishes priorities for the adoption of alarm technology; and at all staffing levels, practices are established to share information about alarm-related incidents, prevention strategies, and lessons learned. This section reviews efforts to address alarm fatigue through improving safety culture; clinical outcome measures and provider perceptions, as well as barriers and facilitators to implementation, are examined.

13.1.2 Methods

Two databases (CINAHL® and MEDLINE®) were searched for articles published from 2008 to 2019 using the terms "alarm fatigue," "alarm management," and related synonyms, as well as "safety culture," "protocol," "leadership," and other similar terms. The initial database search yielded 117 results. Once duplicates were removed and 8 additional relevant articles from selected other sources were added, a total of 114 articles were screened for inclusion. Five of the eight additional articles from other sources were identified through a manual search of the Joint Commission, ECRI Institute, and AAMI websites for relevant case studies. Due to the overlap between Safety Culture and Risk Assessment for this topic, three additional articles from other sources were identified from the Risk Assessment literature search that were also relevant for this patient safety practice (PSP), and they were reviewed. After screening the 114 articles, 63 full-text articles were retrieved, of which 17 in total were selected for inclusion in this review. Articles were excluded if the outcomes were not relevant to this review, the article was out of scope, or the article did not describe an intervention.

Finally, after reviewing the initial set of full-text articles retrieved, we ran one additional search with the term "alarm desensitization" and related synonyms, which did not yield any relevant results.

General methods for this report are described in the Methods section of the full report.

For this patient safety practice, a PRISMA flow diagram and evidence table, along with literature-search strategy and search-term details, are included in the report A through C appendixes.

13.1.3 Review of Evidence

A summary of key findings related to alarm management safety culture is located in the Key Findings box. The following section reviews the applicable studies in more depth by measure type. Of the 17 studies included in this review, 10 were QI initiatives, 5 were case studies, 1 was a quasi-experimental study, and 1 was an observational study. All took place in the hospital setting, with 4 of the 17 studies examining the establishment of safety culture to address alarm fatigue hospital-wide. The remaining 13 studies examined the implementation of this PSP in a specific unit, including the intensive care unit (ICU), progressive care unit (PCU), neonatal intensive care unit (NICU), and telemetry, step-down, transplant, cardiology, surgical, and surgical orthopedic units.

Key Findings:

Clinical Outcomes

- Eight studies found a decrease in the total number of alarms, including three studies that reported a decrease in the number of false alarms.
- Two studies found an overall reduction in noise level post-intervention in the study units.

Facilitators

- Securing buy-in from staff at all levels is key to achieving culture change.
- Cultural change was necessary throughout the unit to transition from alarm management being considered a nursing concern to everyone taking responsibility for alarm management.
- Changing the culture to recognize that patient safety is everyone's responsibility and each staff member has the duty to address alarms was an important step in improving care.

To evaluate the impact of implementing safety culture elements on alarm fatigue, the studies included in this review measured both clinical outcomes that are indicators of alarm fatigue as well as behavioral outcomes related to providers' perceptions of culture change.

13.1.3.1 Clinical Outcomes

Clinical outcome measures for alarm fatigue were reported in eight studies. Outcomes in these studies included total number of alarms, alarm rate, number of false alarms, and noise level. Clinical alarms are intended to provide a quick patient assessment; however, a high abundance of alarms, the majority of which are often false alarms, diminishes their efficacy. To address this abundance, the studies included in this review primarily sought to decrease overall alarm burden. The authors of the included studies note that they first identified which types of alarms were the greatest contributors to alarm fatigue and targeted those, so a decrease in overall number of alarms is consider a positive outcome.

De Vaux et al. observed 23–26 patients in a step-down unit over a 2-week period pre-implementation of the American Association of Critical-Care Nurses' (AACN) clinical toolkit to improve safety of alarm management and at three points post-intervention. The authors found that the total number of alarms decreased from 251 pre-intervention to 12 at 6 months post-intervention. They also found a decrease in the number of false alarms from 201 to 12 and a decrease in nonactionable alarms from 122 to 6 over the same time period.[2] Dandoy et al. reported that during implementation of a standardized cardiac monitor care process, which included daily electrode changes, daily evaluation of monitor parameters, and timely discontinuation of monitor use, the median number of cardiac alarms per monitored patient day decreased from 180 to 40 over 11 months, and the median number of false alarms decreased from 95 percent to 50 percent.[3] Rayo et al. found that after implementing a new continuous cardiac monitoring policy, the percentage of false alarms decreased from 18.8 percent to 9.6 percent, but the percentage of unnecessary alarms remained consistent.[4]

Five additional studies examined the change in total number of alarms, but did not measure the number of false or nonactionable alarms. A study by Epstein et al. showed that over 4 months the pilot

telemetry unit successfully lowered its total number of alarm signals by 69 percent.[5] In addition, Graham and Cvach found a 43-percent reduction in physiological monitor alarms,[6] Vockley found a 30-percent decrease in alarm signals,[7] and Whalen et al. found an 89-percent reduction in total number of audible alarms per week.[8] Finally, Srinivasa et al. reported a 54-percent reduction in the total alarm rate (alarms per bed per day).[9] Many of the interventions included in these studies were multifaceted so it is difficult to conclude which elements contributed to the changes in alarm frequency. Some of the facilitators, however, included small tests of change, educating staff on better alarm management, and empowering nursing staff to change default alarm settings. Additional facilitators are summarized below.[9]

In addition to number of alarms, alarm volume was used as a clinical outcome measure of alarm fatigue. Excessive alarm noise creates an unpleasant work environment and contributes to alarm fatigue as staff become desensitized to the white noise. Two studies measured noise level before and after an alarm-reduction patient safety intervention, and both found overall reductions in noise level in the study units. Srinivasa et al. reported that average noise in decibels (dB) for the left wing and main hallway of a surgical telemetry unit dropped from 58.94dB to 57.84dB and from 58.04dB to 54.43dB, respectively, pre- to post-intervention.[9] Whalen et al. found that the decibel level narrowed from a range of 54–90dB to 60–72dB after implementing a pilot QI project in a medical cardiology unit.[8]

13.1.3.2 Behavioral Outcomes

Safety culture is typically measured by surveying clinicians.[1] In this review, eight studies included surveys measuring physician and clinical staff perceptions, satisfaction, and understanding of procedures and factors related to implementation of the PSP.

Two studies included surveys exploring alarm fatigue. Results of a survey by Alsaad et al., before and after implementing guidelines and protocols for reducing alarms in cardiac telemetry, found a 27-percent reduction in a score of perceived alarm fatigue.[10] In a survey by Ketko et al., most respondents reported they felt that alarm fatigue was being addressed and alarm frequency decreased as a result of the implementation of processes for safe alarm management and response.[11]

Two studies asked nurses about their perception of alarm noise. Graham and Cvach found that nurses perceived the unit's overall noise level as lower after implementing changes to reduce alarms.[6] Whalen et al. found that the percentage of nurses who assessed the noise level on the unit as acceptable increased from 0 percent to 64 percent post-intervention.[8]

Three studies included surveys that asked clinicians about their perceptions and behaviors related to alarm management processes. The results from these surveys were mixed. For example, in a survey by Cameron and Little, 66 percent of nurses agreed or strongly agreed that they had improved their alarm management practices as a result of the new alarm policy, and there was a significant improvement in nurses selecting the appropriate intervention to manage an alarm. The same study, however, also reported that nurses' perceptions about alarms were more negative after the initiative in terms of reducing attention to patients, feeling overwhelmed by alarms, alarms contributing to stress levels, and situations requiring alarm disabling.[12]

Petersen and Costanzo, surveyed nurses about their knowledge of their hospital's initiatives to reduce alarm fatigue, and found that 58 percent of responding nurses felt that clinical policies and procedures were effectively used to manage alarms. However, only 15 percent of responding nurses recognized that a new alarm management team had been implemented to assess current needs, edit policies, decrease

alarm numbers, and change the culture of alarm management. In addition, only 19 percent of responding nurses recognized that new technology had been implemented to improve clinical alarm safety. Overall, the authors concluded that these survey results showed a lack of education in alarm management and therefore incorporated training into future hospital improvement intiatives[13]

Clinicians' confidence in addressing alarms may improve after implementation of an alarm management PSP. For example, after hospital-wide alarm management competency training, Allen et al. surveyed nurses and found a 13-percent decrease in the number of nurses who rated themselves as not confident in one or more aspects of monitor functionality, such as customizing patient alarms or reviewing alarm settings.[14]

13.1.3.3 Economic Outcomes

Only one included study measured outcomes of safety culture alarm management initiatives related to cost. Alsaad et al. calculated changes in cost (measured in dollars) for patients who were originally monitored by cardiac telemetry but were downgraded to being non-monitored after implementing new protocols. In accordance with the protocols, patients who were monitored with no clinical indications for cardiac telemetry were discontinued from monitoring and downgraded to a different inpatient status, resulting in a 42-percent cost reduction.[10]

13.1.3.4 Unintended Consequences

13.1.3.4.1 Negative

Authors of the studies we reviewed did not indicate many unintended negative consequences of implementing elements of safety culture to address alarm fatigue. McGrath et al. hypothesized that implementing wireless sensors would decrease the alarms caused by staff removing sensors to allow patients to move around; however, results showed a greater than expected increase in non-clinical alarms, which are associated with system status and device operation. Despite this increase, there was not a significant increase in clinical alarm rates per hour monitored, and overall alarm rates were still below a level where the authors judged that alarm fatigue would be a concern. In addition, the authors note that an increase in total number of alarms was expected in their study, because patients were monitored for a more continuous period as a result of the intervention.[15]

13.1.3.4.2 Positive

Positive unintended consequences were mentioned by a few authors. De Vaux et al. reported an incidental finding that default-setting parameters were more often customized to match a patient's clinical condition after the intervention. Pre-intervention, 39.0 percent of alarms were customized to diverge from the preset default settings (e.g., using a higher threshold to trigger the alarm), and after implementing guidelines for alarm management, 87.5 percent of alarms were customized.[2]

Vockley and Kloewer noted that introducing a new technology into a healthcare setting typically increases alarm burden, but the researchers observed that after introducing a continuous surveillance monitoring system, there were fewer and more meaningful alarms, and staff expressed higher trust that the system would relay clinically significant alarm signals, therefore easing the burden.[16]

13.1.4 Implementation

13.1.4.1 Summary of Evidence on Implementation

Improving the culture of safety in a unit or hospital can be difficult, and this PSP includes a variety of interventions involving commitment to a culture of safety by all staff at all levels, as well as changes to processes, workflows, and policies that embody this commitment. The studies we reviewed implemented a variety of changes that were specific to the unique needs of the hospital, unit, or type of monitor/alarm. Across these varied initiatives, some common themes of facilitators and barriers emerged.

13.1.4.2 Facilitators and Barriers

13.1.4.2.1 Facilitators

Buy-in, especially from leadership, can greatly facilitate an effective change in safety culture. Eight of the 17 studies directly mentioned that leadership was involved in developing and implementing the safety culture alarm fatigue PSP. For example, Jahrsdoerfer noted that hospital leaders decided to update existing alarm management processes to maximize use of modern technology.[17] Cameron et al., Rayo et al., and Whalen et al. also highlighted that strong leadership support was a key factor in successful implementation.[4,8,12] In addition to leadership commitment, securing buy-in from staff at all levels facilitates culture change. Whalen et al. noted that nurses became strong advocates of the project, which resulted in sustained change,[8] and Graham and Cvach attributed achieving true culture change in alarm management to having complete buy-in from staff.[6] AAMI also noted that a key to success was that technology matched the culture of change, and there was strong support from all stakeholders involved.[18] A survey respondent in a study by Petersen and Costanzo stated that an important step in improving care is changing the culture to recognize that patient safety is everyone's responsibility and each staff member has the duty to address alarms.[13] Echoing this, Ketko et al. noted that cultural change was necessary throughout the unit to transition from alarm management being considered a nursing concern, to everyone taking responsibility for alarm management.[11]

Another common theme identified as an implementation facilitator was the effort to standardize procedures. For example, Allen et al. stated that the health system's leaders, after recognizing a lack of standardized protocols, established a new protocol and adopted an evaluation tool across all departments in the system.[14] In addition, Graham and Cvach noted that the hospital did not have standards for alarm response before the QI project began, but as a result of the initiative, standardized education and a hospital-wide monitor protocol were implemented to improve alarm management.[6] Finally, Dandoy et al. noted that the aim of their project was to implement a standardized, team-centered process for cardiac monitoring to decrease nuisance alarms.[3]

13.1.4.4.2 Barriers

If a newly implemented alarm management process is not clearly defined or training is incomplete, adherence by clinical staff can be suboptimal. For example, Dandoy et al. found that when the cardiac monitor care process was first implemented, compliance was 33–43 percent. After roles and responsibilities were clearly defined, however, compliance increased to 73–98 percent.[3] In addition, Cameron and Little, Epstein et al., and Vockley and Kloewer noted the importance of ongoing training to educate providers about alarm management.[5,7,12]

13.1.4.3 Resources To Assist With Implementation

The AAMI Foundation National Coalition for Alarm Management Safety brings together stakeholders to discuss strategies to improve alarm management, and provides resources and toolkits for healthcare organizations to begin work in this area. The ECRI Institute developed The Alarm Safety Handbook and Workbook, which outline the measures healthcare facilities should take to effectively manage alarms. The National Association of Clinical Nurse Specialists Alarm Fatigue Toolkit provides recommendations and resources to help clinical nurse specialists effectively manage alarms and combat alarm fatigue.

13.1.5 Gaps and Future Directions

The current literature on this PSP primarily concerns QI initiatives and case studies; higher quality studies could help to better understand the impact of implementing elements of safety culture to address alarm fatigue. In addition, because efforts to improve safety culture typically involve multiple elements and are often part of a larger hospital-wide initiative, it is difficult to know which intervention(s) are most responsible for reducing alarm fatigue. The studies we reviewed had small sample sizes and focused on one hospital or specific unit, and often one type of monitor/alarm, and may have limited generalizability.

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13.2 Patient Safety Practice 2: Risk Assessment

13.2.1 Practice Description

Risk management is crucial to promoting safer healthcare and proactively identifying, prioritizing, and mitigating patient safety risk. Many national organizations recognize that conducting a baseline alarm assessment to understand current needs and conditions contributing to alarm fatigue is an important step in alarm management. For example, the AAMI Foundation recommends, as one of its Ten Ideas for Safe Alarm Management, engaging a multidisciplinary team to prepare an alarm inventory risk analysis and gap analysis that identifies patient safety vulnerabilities that could be amenable to change.[1] In addition, an element of performance for the Joint Commission's National Patient Safety Goal on Alarm Management is to "identify the most important alarm signals to manage based on: input from the medical staff and clinical departments; risk to patients if the alarm signal is not attended to or if it malfunctions; whether specific alarm signals are needed or unnecessarily contribute to alarm noise and alarm fatigue; potential for patient harm based on internal incident history; and published best practices and guidelines."[2] Conducting an alarm risk assessment can include evaluating medical devices and computer systems, including the default alarm settings; assessing patient satisfaction (e.g., sleep interruption from nuisance alarms); and assessing the physical environment to determine whether clinically significant alarm signals are audible to staff. In addition, healthcare settings may use data from event reporting systems to identify actual or near-miss harm reported by staff as a method of risk assessment. This section briefly reviews studies in healthcare facilities that engaged multidisciplinary alarm management teams to conduct alarm risk assessments.

13.2.2 Methods

Two databases (CINAHL® and MEDLINE®) were searched for articles published from 2008 to 2019 using the terms "alarm fatigue," "alarm management," and related synonyms, as well as "management," "risk assessment," "interdisciplinary," "committee," and other similar terms. The initial database search yielded 186 results. Once duplicates were removed and seven additional relevant articles from selected other sources were added, a total of 167 articles were screened for inclusion and 47 full-text articles were retrieved. Of those, 13 were selected for inclusion in this review. Articles were excluded if the outcomes were not relevant to this review, the article was out of scope, or the article did not describe an intervention.

To identify additional articles from other sources, we conducted a manual search of the Joint Commission, ECRI Institute, and AAMI websites for relevant case studies. This yielded three articles that we included. In addition, due to the overlap between Safety Culture and Risk Assessment for this topic, we identified three articles from the Safety Culture literature search that are also relevant for this PSP and were reviewed. Finally, we scanned the reference sections of all full-text articles retrieved and, as a result, identified one additional article for inclusion. These seven articles brought the total number of articles included in this review to 13.

Finally, after reviewing the initial set of full-text articles retrieved, we ran one additional search with the term "alarm desensitization" and related synonyms, which did not yield any relevant results.

General methods for this report are described in the Methods section of the full report.

For this patient safety practice, a PRISMA flow diagram and evidence table, along with literature-search strategy and search-term details, are included in the report A through C appendixes.

13.2.3 Review of Evidence

Of the 13 studies included in this review, 10 were QI initiatives and 3 were case studies. All took place in the hospital setting, with 3 of the 13 studies examining the implementation of this PSP hospital-wide. The remaining 10 studies examined establishing a multidisciplinary alarm management committee to conduct ongoing alarm risk assessment in a specific unit, such as the ICU, PCU, NICU, or step-down, transplant, cardiology, surgical, or surgical orthopedic units.

All the articles included in the review of this PSP are also included in Chapter 17, Section 17.2, Safety Culture. After reviewing the literature, we found that in all the relevant studies, hospitals engaged teams to conduct an alarm fatigue risk assessment as a component of a larger QI project or system-wide initiative. In fact, for many of the studies, the team's assessment informed the creation and implementation of the safety culture initiative. Due to this overlap, many of the clinical and behavioral outcome measures for alarm fatigue detailed in the previous section are the same for this review. Highlights from these findings are briefly summarized in the Key Findings box. In addition to the outcomes measuring indicators of alarm fatigue, these studies also included outcomes from the alarm risk assessments. They are briefly described below.

13.2.3.1 Multidisciplinary Risk Assessment

The multidisciplinary teams assembled for these initiatives conducted risk assessments to understand the current state of alarm management and identify which alarms contributed most to alarm fatigue. Three studies mentioned specific methods used to conduct the analysis. In a study by Vockley, a multidisciplinary team evaluated the use of cardiac alarm technology using Failure Mode and Effects Analysis, which is a step-by-step approach for identifying errors and studying their potential consequences.[3] Similarly, a team in a study by AAMI conducted a Failure Mode and Effects Analysis, and Cameron and Little studied a team using Failure Mode Effects and Critical Analysis to assess alarm risk.[4, 5] In a study by De Vaux et al., an alarm management team used a gap analysis assessment tool from the American Association of Critical-Care Nurses to assess alarm safety.[6]

The results from these multidisciplinary assessments varied due to the diverse range of hospital units and monitors that were studied. For example, a QI team, in a study by Cameron and Little, conducted a hospital-wide analysis and found that telemetry, pulse oximetry, intravenous pumps, and the fire alarm system were the most troublesome for nursing staff.[5] In a study by Whalen et al., a telemetry task force learned from clinicians that two types of arrhythmia alarms often created unnecessary noise because they occurred frequently but were rarely clinically significant.[7] De Vaux et al. reported that as a result of an alarm management team's assessment, audible alarms from bedside physiologic monitors were identified as the largest contributor to noise level in the medical ICUs.[6]

Key Findings:

Clinical Outcomes

- Five studies found a decrease in the total number of alarms.
- Three studies reported a decrease in the number of false alarms.
- Two studies found an overall reduction in noise level post-intervention in the study units.

In addition to assessing the types of monitor that contribute to alarm fatigue, some studies focused on a specific type of alarm, and multidisciplinary teams assessed the current practices for managing those

alarms. For example, Dandoy et al. noted that a team reviewed the cardiac monitor care process to identify gaps in practice and areas for improvement.[8] Vockley reported that a team found that 40 percent to 50 percent of patients in the general medical and surgical units were monitored on cardiac telemetry, but there were no consistent criteria about which patients should be placed on cardiac telemetry monitoring.[3]

13.2.4 Implementation

13.2.4.1 Summary of Evidence on Implementation

Many of the barriers and facilitators to engaging a multidisciplinary team to conduct an alarm risk assessment are similar to those for implementing elements of safety culture to address alarm fatigue—most importantly, support from leadership and staff. This section reviews additional implementation facilitators that are specific to alarm risk assessment.

13.2.4.2 Facilitators

Engaging a team that includes stakeholders from different disciplines is an important facilitator of effectively assessing alarm fatigue risk. All the studies included in this review specifically mentioned that the multidisciplinary assessment team included representatives beyond just clinical staff, and several noted the important contributions of these additional stakeholders. For example, AAMI noted the importance of including biomedical, human factors, and cognitive systems engineers on the team to ensure that changes in a surveillance system caused no undue burden for patients and clinicians.[4] Epstein et al. found that a vendor representative on the alarm management committee helped ensure that the hospital was compliant with the alarm management goal, provided current best practice recommendations, and assisted with analysis of device integration.[9] Rayo et al. found that human factors engineers, clinicians, and IT professionals working together led to solutions that optimized usability and mitigated risks. In addition, guidance from human factors engineers led the team to measure true, false, and unnecessary alarms, which are reliable predictors of alarm response.[10] In addition, Ketko et al. noted that acknowledging alarm management as a collaborative effort was an important first step in the initiative.[11]

The decision to engage a team and conduct a risk assessment was often in response to a specific adverse patient event or external influence. For example, Vockley notes that after two sentinel events involving alarm signals at the studied hospital, a team was formed to investigate the incidents and conduct a larger assessment of the current alarm use practices.[3] Whalen et al. stated that leadership convened a telemetry task force to explore the issue of alarm fatigue after reports of sentinel events at other institutions.[7] Four studies (Cameron and Little, De Vaux et al., Epstein et al., and Rayo et al.) noted that alarm management teams were formed in response to and with the goal of meeting the Joint Commission's National Patient Safety Goal on Alarm Management.[5,6,9,10]

13.2.5 Gaps and Future Directions

As with safety culture, the studies we reviewed focused on one hospital or specific unit, so may have limited generalizability. Despite this, the research presents moderately strong evidence demonstrating the value of conducting a multidisciplinary risk assessment to address alarm fatigue.

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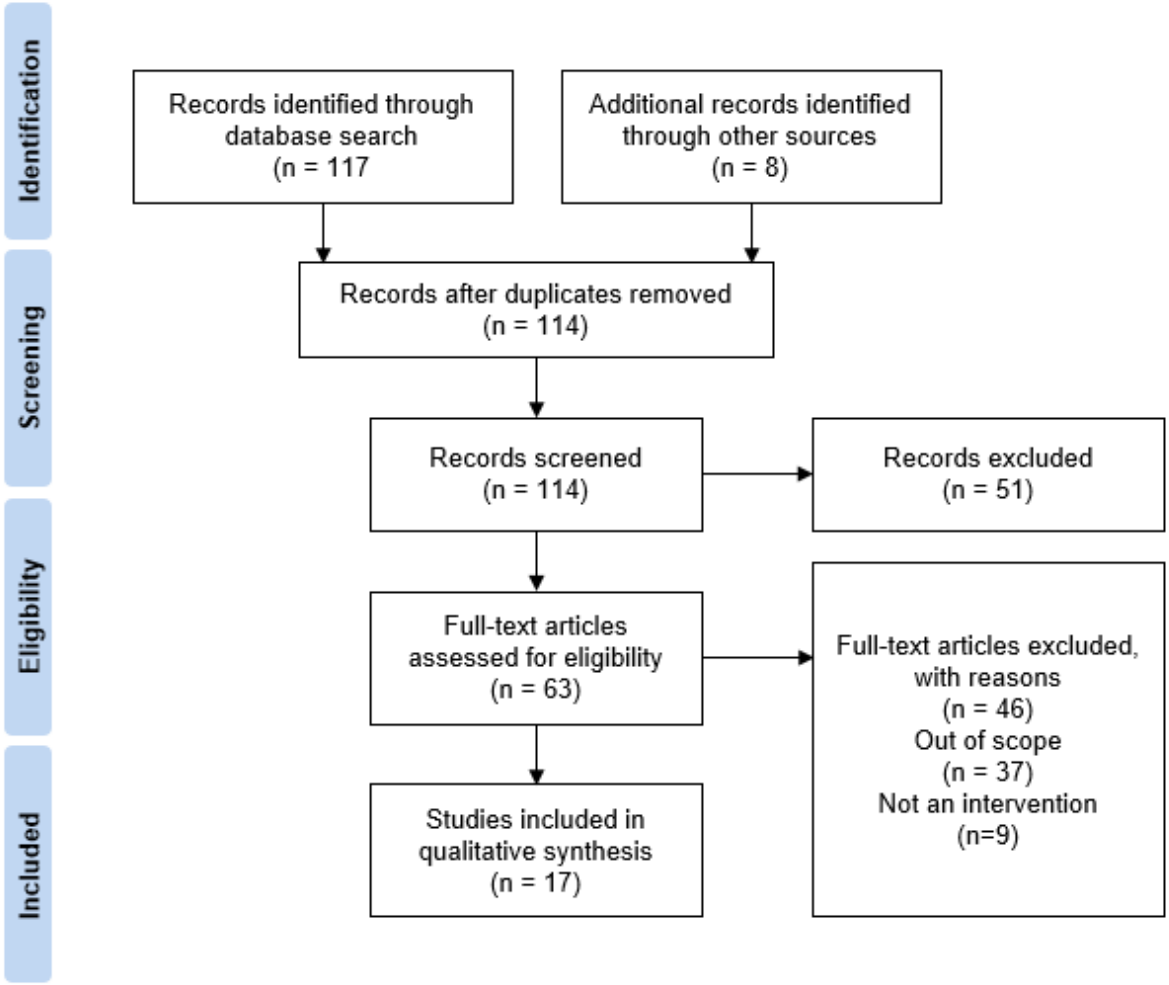
Conclusion and Comment

The two PSPs reviewed in this chapter aim to address alarm fatigue by implementing hospital- or unit-wide initiatives to target nonactionable, nuisance alarms and decrease overall alarm burden. The review of evidence shows that implementing elements of safety culture can lead to a decrease in the total number of alarms, number of false alarms, and overall alarm noise level; however, since these initiatives often involve multiple components, it is difficult to know which intervention(s) have the greatest impact. The evidence also shows moderately strong support for conducting risk assessments to understand the current state of alarm management and identify which alarms are the greatest contributors to alarm fatigue. The results of these risk assessments should be used to inform the implementation of processes for safe alarm management and priorities for adoption of alarm technology. Investing in training and education for care providers on new technology as well as ensuring buy-in at all levels and engaging multidisciplinary teams are key to effectively implementing these strategies to reduce alarm fatigue.

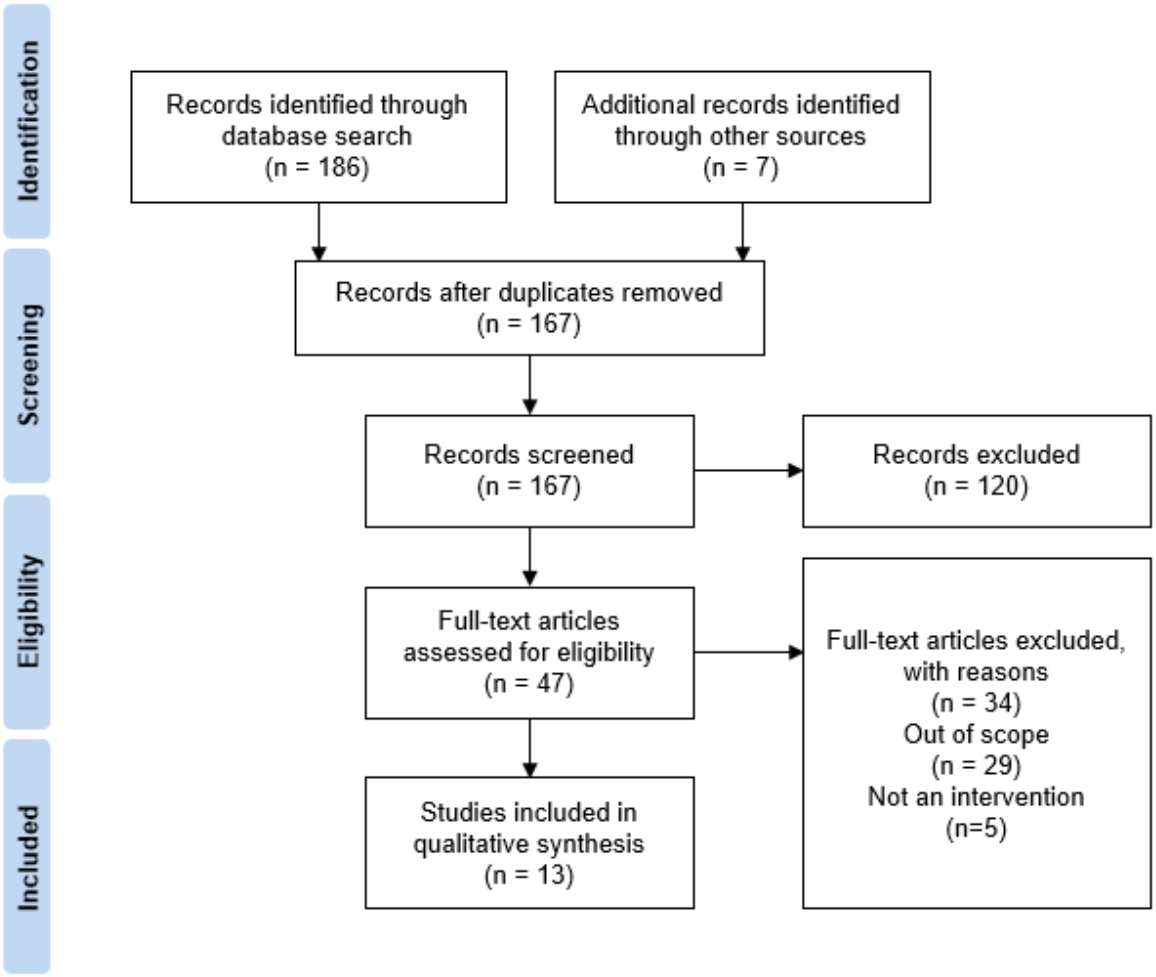
Appendix A. Alarm Fatigue PRISMA Diagrams

Figure A.1: Alarm Fatigue, Safety Culture—Study Selection for Review



PRISMA criteria described in Moher D, Liberati A, Tetzlaff J, et al. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med. 2009 Jul 21;6(7): e1000097. doi:10.1371/journal.pmed1000097.

Figure A.2: Alarm Fatigue, Risk Assessment—Study Selection for Review



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Appendix B. Alarm Fatigue Evidence Tables

Table B.1: Alarm Fatigue, Safety Culture–Single Studies

Note: Full references are available in the Section 13.1 reference list.

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
AMMI, 2013[18]	Implemented a systems approach, which involved a cycle of continuous improvement, including prioritizing improvement, designing and testing change, implementing change, and continuing to measure performance.	Case study	Dartmouth-Hitchcock Medical Center. Medical-surgical orthopedic unit (36 beds).	Rescue events decreased from 3.5 per 1,000 patient days before implementation to 1.2 afterward. Intensive care unit (ICU) transfers decreased from 5.6 per 1,000 patient days to 2.9. Documented high patient and clinical acceptance of the surveillance monitoring.	Not provided	Based on results, expanded surveillance monitoring to additional adult medical-surgical units and pediatric and adolescent unit. One of the researchers noted that "the key to success was that the technology was matched with a culture of caring."	High: case study and not peer reviewed	Pulled from Association for the Advancement of Medical Instrumentation (AAMI) Safety Innovations Series—manual search Included in PSP 2

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Allen et al., 2013[14]	Adopting the lessons of the pilot, the team developed an evaluation tool to assess staff competency in identifying and responding to alarm systems management. Recognizing the lack of standardized protocols, the health system's leadership established its own protocol and adopted this tool as universal and standard across all departments in the system.	Case study	University of Pittsburgh Medical Center (UPMC), Presbyterian Hospital (737 beds).	Overall alarm signal time was reduced by approximately 80%. Since this protocol was put in place, there has been no increase in adverse patient events. Post-survey results of nurses showed a 13% decrease in number of nurses who rated themselves not confident in one or more aspects of monitor functionality.	Not provided	As nursing staff in the pilot units became more comfortable with the new process, interest among hospital leadership grew. Alarm management at UPMC is viewed as a team effort with bedside and clinical care nurses, clinical engineers, clinical directors, unit directors, and risk management personnel all having a stake in the success of initiatives that seek to improve patient safety. through alarm management.	High: case study and not peer reviewed	Pulled from AAMI Safety Innovations Series—manual search

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Alsaad et al., 2017[10]	Team of progressive care unit (PCU) nurse manager, nurse educator, and medical transcription manager participated in the creation and dissemination of clear guidelines and protocols for telemetry use. Protocols developed included: a flow diagram to assist providers in the determination of a patient's needs, a stepwise detailed process on how to check encounters to ensure the appropriateness of cardiac telemetry (CT) monitoring, and standard protocol for electrode placement.	Quality improvement (QI) study. Collected pre-post intervention data. Used different statistical methods to report the study results, including paired t-test, $\chi 2$, and Mann-Wilcoxon equation.	Mayo Clinic campus in Jacksonville, FL. PCU (27 beds).	Nurses reported 27% perceived decrease in alarm fatigue post-intervention and 10% reduction in CT assignment post-intervention. Significant cost reduction was achieved by implementing the protocols. No significant differences in mortality rate before and after intervention.	Not provided	Development of a clear and applicable protocol for the appropriate use of CT in non-cardiac-related hospitalized patients has led to fewer monitored patients and fewer telemetry alarms, which resulted in less alarm fatigue and reduced cost.	Moderate	Included in Patient Safety Practice (PSP) 2

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Cameron and Little, 2018[12]	Hospital leadership directed the QI department to develop a plan to meet the Joint Commission National Patient Safety Goal (NPSG). Formed an alarm management committee that developed an alarm policy and planned an education program for nurses on alarm management.	QI study using pre-/post-test design to evaluate the alarm management education program and nurses' perceptions and practices related to clinical alarms. Likert questions were analyzed using Wilcoxon signed-rank test with a confidence interval of 95%. Participants: 417 nurses from all departments (215 completed post-test).	Florida acute care hospital (257 beds).	Significant improvements reported in 8/12 of the questions related to alarm perceptions. Sixty-six percent of nurses who completed post-test reported they strongly agree or agree they have improved their alarm management practices. Nurse-initiated collaborative team-based alarm practices significantly improved, including consulting a provider for individualized monitor settings and judicious use of telemetry monitoring versus unnecessary use. Results also showed significant improvement in selecting appropriate intervention.	Alarm perceptions were more negative post-test in 4 questions related to: alarms reducing attention to patients, feeling overwhelmed by alarms, alarms contributing to nurses' stress level, and some situations requiring alarm disabling.	The findings of this QI project indicate that nurses are receptive to education on alarms, and changed their perceptions and practices based on the education program and a new policy. Through strong leadership and a team approach, hospitals have the opportunity to improve patient safety while improving the work environment, patient care, and overall staff morale. Leadership, equipment, policies, and staff education are the four cornerstones in developing and implementing effective alarm management evidence-based practices in a hospital setting. Hospitals should have policies and education in place to empower nurses to implement alarm management best practices and standards set forth by professional organizations.	Moderate	Included in PSP 2

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Dandoy et al., 2014[3]	Multidisciplinary alarm oversight task force created and implemented a standardized, team-centered, cardiac monitor care process (CMCP).	QI study using Model for Improvement to design, test, and implement changes. Tested hypotheses using PDSA (plan, do, study, act) measures.	Cincinnati Children's Hospital Medical Center. Bone marrow transplant unit (24 beds).	During implementation the median number of alarms per patient-day decreased from 180 to 40. Median number of false alarms on the floor fell from 95% to 50%. Compliance with the CMCP remained stable at a median of 38% through PDSA testing. Once roles and responsibilities were determined and the process was clearly defined, full implementation continued and the unit's overall compliance with the CMCP increased to a median of 95%.	Not provided	Found significant decrease in the number of alarms per monitored patient with the implementation of a standardized process. Fewer false alarms allow staff to address alarms more promptly.	Moderate	Included in PSP 2

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
De Vaux et al., 2017[2]	Medical critical care leadership team organized an alarm management team. Leadership applied recommendations of Association of Critical-Care Nurses' clinical toolkit and distributed materials to staff to provide guidelines for alarm management.	QI study using direct observation methods once pre-intervention and at three points within 6 months post. Sample size of patients observed varied from 23 to 26 at data collection points.	Yale New Haven Hospital, York Street Campus. Two step down units (28 beds each).	Total alarms decreased from 251 in March 2014 to 12 in Feb 2015. False alarms decreased from 201 in March 2014 to 12 in Feb 2015. Alarm setting customization increased from 39% pre-intervention to 87.5% post. No adverse patient events were reported during the observational time period.	Not provided	Authors attributed increases in customization to cumulative effect of staff education and best practice interventions. Team shared findings with leadership, and as a result the St. Raphael campus of New Haven Hospital adopted default alarm changes.	Moderate	Included in PSP 2

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Epstein et al., 2016[5]	Implemented a new lead hygiene policy and procedure, and educated staff on how to better manage telemetry station and patient-specific alarm settings.	Case study	NCH Healthcare System. Pilot telemetry unit.	Over 4 months, the pilot unit lowered its total number of alarm signals by 69% without a negative impact on patient safety.	Not provided	NCH discovered that a key factor in successful alarm management is continuing education for basic monitor and device management when setting device alarms. NCH has been successful in sustaining its alarm management process by constantly monitoring and responding to near real-time alarm data in the shift report. One researcher highlighted this by noting that "by driving our alarm management process with data, we know what we need to target and if we're making improvements."	High: case study and not peer reviewed	Pulled from AAMI Safety Innovations Series—manual search Included in PSP 2

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Graham and Cvach, 2010[6]	The Alarm Management Task Force tested interventions that informed the development of an interdisciplinary hospital-wide cardiac monitoring protocol. The medical PCU's (test unit) Comprehensive Unit-Based Safety Program (CUSP) team oversaw this project and led the small tests of change. The goals of a CUSP team are to (1) improve the culture of safety on the unit, (2) allow staff to focus safety efforts on unit-specific problems, and (3) collect and analyze data to improve patients' safety.	QI project. Collected baseline data and then implemented tests of change. Administered a pre- and post-intervention survey to nursing staff.	Northeastern Academic Medical Center. Medical PCU (15 beds, 30 nurses).	Forty-three percent reduction in critical physiological monitor alarms. Nurses perceived the unit's overall noise level as lower after the intervention.	Not provided	This QI initiative led to standardization of monitor education and implementation of a hospital-wide monitor protocol. Complete buy-in from staff was essential to achieving a true culture change in alarm management. Lessons learned include: (1) unit staff should analyze alarm parameters to determine if they are appropriate; (2) alarm parameters should be set to actionable levels; (3) nurses must be trained to individualize alarm parameters; (4) institutions should establish institution-wide standards for management.	Moderate	Included in PSP 2

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Jahrsdoerfer, 2016[17]	Hospital leadership team made the decision to move beyond its current alarm and event response model to maximize us of new technology. The leadership team collaborated with industry and implemented principles for an effective alarm system to guide its workflow.	Quasi-experimental study. Focus of evaluation was to determine value added of using secondary alarm notification with a unified alarm management technology platform, monitor technician and mobile device.	Large integrated delivery network on the East Coast. 4 units: ICU, progressive care, and two telemetry units (52 beds total).	Leveraging the monitor tech translated to a 68% reduction in alarms sent to the nurse. Overall 76% less alarms dispatched to nurses on their mobile devices.	Not provided	As a result of the reduction in the number of patient monitoring nonactionable alarms that reached nurses' mobile devices, clinical interruption fatigue was reduced. Using middleware alarm technology provided a safety net to ensure that red alarms were not missed by the monitor technician.	High: case study with quasi-experimental design	Pulled from AAMI BI&T journal—manual search
Ketko et al., 2015[11]	Multidisciplinary improvement task force determined patient care practices and systems/operational practices to be key drivers of alarm frequency. Processes to affect these key drivers were identified, and measures were selected and modified to align with those recommended by the Joint Commission.	QI study. Used control charts with many data points and conducted tests of significance.	C.S. Mott Children's Hospital at the University of Michigan. Neonatal ICU.	Modified SANS algorithm for high SpO2 delivery resulted in an immediate and sustained decrease in the escalation of high SpO2 alarms to nursing phones. Results of the survey regarding attitudes and perceptions in alarm frequency demonstrated that most respondents felt that alarm frequency had improved and alarm fatigue was being addressed.	Not provided	Recognition that alarm management must be a collaborative effort was an important first step—cultural change transitioning from alarm frequency being a nursing concern to everyone taking responsibility was key to successfully developing strategies.	Moderate	Pulled article from manual search of reference section of Jubic, K. 2017 *Strategies for Managing Alarm Fatigue in the PICU Setting* (included in PSP 2 literature pull) Included in PSP 2

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
McGrath et al., 2019[15]	Applied systems-level design and analysis methods to continuous monitoring technology workflow.	Difference in differences observational study.	Two surgical units (71 beds total).	Not a significant difference in the count of clinical alarms per monitored hour after implementation.	Significant increase when alarms per patient day were calculated. Greater than expected increase in non-clinical alarms.	Despite increase in non-clinical alarms, overall alarm rates were still below threshold where alarm fatigue would be a concern. Importance of adopting a system-level design and analysis, which provided a foundation for effective workflow redesign, change management, and measurement.	Moderate	Pulled article from PSP 2 literature search

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Petersen and Costanzo, 2017[13]	Through this project a policy was developed by the alarm management team to ensure effective clinical alarm systems and the promotion of patient safety.	QI study with convenience sampling to understand nurses' perceptions of alarm fatigue and implement interventions that improve safety. Healthcare Technology Foundation's Clinical Alarms Committee Survey was sent to 31 nurses and 14 support staff (83.8% operational response rate).	Mary Lanning Healthcare (acute care facility). ICU and progressive care unit (29 beds total).	One nurse noted that patient safety is everyone's responsibility, and this change in philosophy and culture may be the next best step in improving the care patients receive via alarm management.	When surveyed about knowledge of Mary Lanning Healthcare's initiatives to improvement alarm fatigue, only 15% of nurses recognized that the alarm management team was implemented to assess current needs, edit policies, decrease overall alarm numbers, and change the culture of alarm management. Only 19% of nurses recognized that new technology had been implemented to improve clinical alarm safety.	Survey findings identified the need for alarm management assessment, policy creation, staff training, and continued improvement. Mary Lanning Healthcare implemented a variety of change initiatives based on assessment, current needs, nurse perception, and evidence-based practice.	Moderate	Included in PSP 2

Rayo et al., 2016[4]	Secured leadership support and created an alarm management task force to develop and implement a new continuous cardiac monitoring policy. Aim of the policy was to change the default organizational culture with regard to monitoring. This initiative was identified as a high priority by the institutional leadership including the chief executive officer (CEO), chief financial officer (CFO), and chief operating officer.	Retrospectively collected data from an institutional data warehouse for the 12-week periods before and after the intervention was implemented. Percentages of true, false, and unnecessary alarms were collected by conducting six 2-hour observations across three different units.	Midwest tertiary care health system. Intervention was implemented in 5 hospitals, affecting 37 medical-surgical, cardiac, critical care, and hybrid units (over 1,000 beds total).	False alarm percentage decreased from 18.8% to 9.6% pre- to post-intervention. Percentage of unnecessary alarms remained consistent between the pre- (46.2%) and post-intervention (46.7%) periods. When comparing hospital-wide data before and after implementation, average cardiac monitoring rate decreased 53.2%, weekly monitoring rate decreased 15.5%, and emergency department boarding rate decreased 36.6%.	Not provided	Study indicates that when collaboration across a diverse team is coupled with strong leadership support, policies and procedures such as this one can improve clinical practice and patient care. Results suggest that the development and communication of this new policy safely reduced the length of time that patients spent on continuous cardiac monitoring. Factors of successful implementation include strong leadership support and widespread engagement of staff. Human factors engineers worked closely with clinicians and information technology (IT)professionals from the beginning, resulting in policy and technology solutions explicitly designed to optimize usability and mitigate the risk of increased workload and other unintended consequences sometimes associated with healthcare technology.	Moderate	Included in PSP 2
Srinivasa et al., 2017[9]	Goal of this QI project was to facilitate an environment of care	QI study performed using two	Northeast healthcare facility,	An 84% reduction in the premature ventricular	Not provided	Factors that contributed to the success of reducing	Moderate	Included in PSP 2

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
	in which nurses are tuned into cardiac telemetry alarms that are clinically significant so more efficient patient care may be provided for truly actionable events.	decision analysis models: fishbone analysis and Model for Improvement framework. Collected baseline and post-intervention alarm load and noise data.	surgical telemetry unit (24 beds).	contractions alarm rate and a 54% reduction in the total alarm rate. There was also an overall noise reduction on the surgical telemetry unit related to the cardiac telemetry alarms. Pre-intervention the average noise in decibels (dB) for the left wing and main hallway was 58.94 dB and 58.04 dB, respectively. Post-intervention it dropped to 57.84 dB and 54.43 dB, respectively.		alarm load and alarm fatigue: (1) Change was integrated into the unit with very little interruption in the flow of the unit. (2) Stakeholder involvement and buy-in from beginning to end. (3) Joint Commission Sentinel alert and subsequent establishment of NPSG on Alarm Management enabled vigorous administrative support and resources required to successfully lead this project.		

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Vockley, 2012[7]	After two sentinel events, the hospital's leadership and the physician, nursing, and clinical engineering staff focused comprehensively on alarmed medical devices and discovered inconsistent cardiac telemetry alarm system management. Implemented a centerwide cardiac alarm system management initiative including short-term fixes and long-term innovations.	Case study	Beth Israel Deaconess Medical Center (631 beds).	A 30% decrease in alarm signals. Decrease in amount of time it takes to respond to an alarm.	Not provided	Resulted in a culture of taking action around auditing the standard of care and patient outcomes, and continuing to adjust alarm system parameters to meet clinical practice standards.	High: case study and not peer reviewed	Pulled from AAMI Safety Innovations Series—manual search Included in PSP 2

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Vockley and Kloewer, 2017[16]	Nurse-driven patient safety initiative: nursing leadership team evaluated different technology options and took the time to understand the rationale for more effective and comprehensive patient monitoring. After the nursing leadership selected continuous surveillance monitoring, they educated the hospital's CEO, CFO, and physician leaders and gained support for moving forward.	Case study	Methodist Specialty and Transplant Hospital, San Antonio, TX. Transplant unit (57 bed) and medical-surgical unit (47 bed).	Comparing time spent on traditional collection of vital signs vs. continuous surveillance determined a potential savings of 16.5 hours on surgical unit and 20 hours on transplant unit. Resulted in fewer and more meaningful alarm signals. The units where registered nurses led the charge (took ownership of the new system) had a faster learning curve. For the units that deferred to patient-controlled analgesia pumps (PCAs), the leadership team added extra education and implemented a standard protocol for initial patient setup.	Not provided	After successful launch of continuous surveillance monitoring on its transplant and one medical surgical unit, the hospital began expanding to more medical surgical units. Decision around expansion was based on enhanced patient safety, strong support from clinicians, patient satisfaction, and improvements in clinical workflow efficiency.	High: case study and not peer reviewed	

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Whalen et al., 2014[8]	Boston Medical Center senior leadership convened a multidisciplinary Telemetry Task Force (TTF) in 2008 to evaluate how cardiac telemetry monitoring equipment was being used in clinical areas, identify ways to improve management and utilization, and develop consensus for a common approach to cardiac monitoring. Reconvened the TTF in 2011 to explore the issue of alarm fatigue.	Two-phase study: (1) observation of nursing staff's response to monitor alarms and (2) QI project in pilot unit to respond to largest contributors to alarm fatigue identified in Phase 1.	Boston Medical Center, medical cardiology unit (24 beds).	An 89% reduction in total number of audible alarms per week on pilot unit. Decibel level narrowed from a range of 54–90 dB to 60–72 dB. Percentage of nurses who assessed the noise level as acceptable increased from 0% to 64%.	Not provided	Success of QI study was the result of a multidisciplinary approach with full engagement, support, and commitment of senior leadership, physician colleagues, IT, engineering, and, most importantly, nursing staff. Nurses became strong advocates of the pilot project, which resulted in sustained change and improvement. Engagement of nurses was critical to creating the culture change necessary to manage alarms and minimize alarm fatigue.	Moderate	Pulled article from PSP 2 literature search Included in PSP 2

Table B.2: Alarm Fatigue, Risk Assessment–Single Studies

Note: Full references are available in the Section 13.2 reference list.

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
AMMI, 2013[4]	Multidisciplinary team (patient safety experts, researchers, physicians, nurses, biomedical and human factors engineers, and information technology [IT] experts) to identify and address the challenges with patient-controlled analgesia pump.	Case study	Dartmouth-Hitchcock Medical Center. Medical-surgical orthopedic unit (36 beds).	Rescue events decreased from 3.5 per 1,000 patient days before implementation to 1.2 afterward. Intensive care unit (ICU) transfers decreased from 5.6 per 1,000 patient days to 2.9. Documented high patient and clinical acceptance of the surveillance monitoring.	Not provided	Based on results, expanded surveillance monitoring to additional adult medical-surgical units and pediatric and adolescent unit. Team understood that implementing more advanced, IT-reliant medical equipment systems required a multidisciplinary perspective. Systems approach is a cycle of continuous improvement that includes prioritizing improvement, designing and testing change, implementing change, and continuing to measure performance.	High: case study and not peer reviewed	Pulled from Association for the Advancement of Medical Instrumentation (AAMI) Safety Innovations Series—manual search Included in patient safety practice (PSP) 1

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Alsaad et al., 2017[12]	Multidisciplinary team (MT) was involved in the study at varying levels. Ordering providers including attending physicians, residents, and advanced practice nurses, along with registered nurses and telemetry MT, were included in the educational sessions to familiarize them with the newly created protocols. The progressive care unit (PCU) nurse manager, nurse educator, and MT manager participated in the protocol creation and staff education.	Quality improvement (QI) study collected pre-post intervention data. Used different statistical methods to report the study results, including paired t-test, $\chi 2$, and Mann-Wilcoxon equation.	Mayo Clinic campus in Jacksonville, FL. PCU (27 beds).	Nurses reported 27% perceived decrease in alarm fatigue post-intervention. There was a 10% reduction in cardiac telemetry assignment post-intervention. Significant cost reduction was achieved by implementing the protocols. No significant differences in mortality rate before and after intervention.	Not provided	Study demonstrates that a significant reduction in alarm fatigue and cost can be accomplished through a multidisciplinary team focused on identifying process gaps and closing them.	Moderate	Article was pulled from PSP 1 literature search. Included in PSP 1

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Cameron and Little, 2018[5]	Multidisciplinary alarm management committee was formed with representation from administration, educators, QI, risk management, biomedical engineering, plant operations, and staff nurses. Committee developed alarm policy and planned educational program for nurses on alarm management.	QI study using pre-/post-test design to evaluate the alarm management education program, and nurses' perceptions and practices related to clinical alarms. Likert questions were analyzed using Wilcoxon signed-rank test with a confidence interval of 95%. Participants: 417 nurses from all departments (215 completed post-test).	Florida acute care hospital (257 beds).	Significant improvements reported in 8/12 of the questions related to alarm perceptions. Sixty-six percent of nurses who completed post-test reported they strongly agree or agree they have improved their alarm management practices. Nurse-initiated collaborative team-based alarm practices significantly improved, including consulting a provider for individualized monitor settings and judicious use of telemetry monitoring versus unnecessary use. Results also showed significant improvement in selecting appropriate intervention.	Alarm perceptions were more negative post-test in 4 questions related to: alarms reducing attention to patients, feeling overwhelmed by alarms, alarms contributing to nurses' stress level, and some situations requiring alarm disabling.	The findings of this QI project indicate that nurses are receptive to education on alarms, and changed their perceptions and practices based on the education program and a new policy. Through strong leadership and a team approach, hospitals have the opportunity to improve patient safety while improving the work environment, patient care, and overall staff morale.	Moderate	Article was pulled from PSP 1 literature search Included in PSP 1

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Dandoy et al., 2014[8]	Multidisciplinary alarm oversight task force consisting of key stakeholders, including physicians, nurse practitioners, nursing leadership, registered nurses, patient care assistants, clinical engineering, and patient family representatives. Team reviewed the current cardiac monitor care practice, published recommendations, identified gaps between practice and evidence, and identified areas of improvement.	QI study using Model for Improvement to design, test, and implement changes. Tested hypotheses using PDSA (plan, do, study, act) measures.	Cincinnati Children's Hospital Medical Center. Bone marrow transplant unit (24 beds).	During implementation, the median number of alarms per patient-day decreased from 180 to 40. Median number of false alarms on the floor fell from 95% to 50%.	Not provided	Found significant decrease in the number of alarms per monitored patient with the implementation of a standardized process. Fewer false alarms allow staff to address alarms more promptly.	Moderate	Included in PSP 1
De Vaux et al., 2017[6]	Alarm management team (clinical engineering, Yale School of Nursing, IT, nursing management, physician leadership, and bedside staff) with the goal of meeting the requirements of The Joint Commission (TJC) National Patient Safety Goal (NPSG). Alarm management team used gap analysis assessment tool provided by the American Association of Critical-Care Nurses.	QI study using direct observation methods once pre-intervention and at three points within 6 months post. Sample size of patients observed varied from 23 to 26 at data collection points.	Yale New Haven Hospital, York Street Campus. Two step-down units (28 beds each).	Total alarms decreased from 251 in March 2014 to 12 in February 2015. False alarms decreased from 201 in March 2014 to 12 in February 2015. Alarm-setting customization increased from 39% pre-intervention to 87.5% post. No adverse patient events were reported during the observational time period.	Not provided	The authors attributed increases in customization to cumulative effect of staff education and best practice interventions. Team shared findings with leadership and, as a result, St. Raphael campus of New Haven Hospital adopted default alarm changes.	Moderate	Article was pulled from PSP 1 literature search. Included in PSP 1

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Epstein et al., 2016[9]	In response to TJC NPSG, an alarm management committee began in Feb 2014 and included representation from nursing leadership, education, respiratory therapy, biomed, regulatory compliance, quality, vendor, and risk management. Goal of committee was to ensure that the data gathered from analysis of the alarm environment would find its way to frontline caregivers and managers.	Case study	NCH Healthcare System	Over 4 months, the pilot unit lowered its total number of alarm signals by 69% without a negative impact to patient safety.	Not provided	Findings highlighted the importance of having vendor representation on the committee to ensure that NCH is compliant with the alarm management goal, provide current best practice recommendations, and assist with analysis of operational reports from the device integration system.	High: case study and not peer reviewed	Pulled from AAMI Safety Innovations Series—manual search Included in PSP 1
Graham and Cvach, 2010[13]	Interdisciplinary alarm management task force was created and charged with (1) evaluating excessive equipment alarms that obscure and desensitize clinicians, (2) standardizing the hospital's approach to alarm management, (3) assessing the reliability of secondary or adjunct alarm notification devices, (4) determining the educational needs of clinicians regarding alarm management, and (5) assessing new technology and systems that may improve alarm management.	QI project. Collected baseline data and then implemented tests of change. Administered a pre- and post-intervention survey to nursing staff.	Northeastern academic medical center. Medical progressive care unit (15 beds, 30 nurses).	A 43% reduction in critical physiological monitor alarms. Nurses perceived the unit's overall noise level as lower after the intervention.	Not provided	Lessons learned include: (1) unit staff should analyze alarm parameters to determine if they are appropriate, (2) alarm parameters should be set to actionable levels, (3) nurses must be trained to individualize alarm parameters, and (4) institutions should establish institution-wide standards for management.	Moderate	Included in PSP 1

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Ketko et al., 2015[11]	Multidisciplinary improvement task force (physicians, nurses, respiratory therapists, biomed engineers, IT) developed an alarm management bundle applying strategies to decrease alarm frequency.	QI study. Used control charts with many data points and conducted tests of significance.	C.S. Mott Children's Hospital at the University of Michigan. neonatal ICU.	Modified SANS algorithm for high SpO2 delivery resulted in an immediate and sustained decrease in the escalation of high SpO2 alarms to nursing phones. Results of the survey regarding attitudes and perceptions in alarm frequency demonstrated that most respondents felt that alarm frequency had improved and alarm fatigue was being addressed.	Not provided	Recognition that alarm management must be a collaborative effort was an important first step—cultural change transitioning from alarm frequency being a nursing concern to everyone taking responsibility was key to successfully developing strategies.	Moderate	Pulled article from manual search of reference section of Jubic, K. 2017. *Strategies for Managing Alarm Fatigue in the PICU Setting* (included in PSP 2 literature pull) Included in PSP 1

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Petersen and Costanzo, 2017[14]	Multidisciplinary alarm management team, including nursing, clinical staff, critical care director, respiratory therapy, biomedical, and engineering staff. Team was established as part of a series of system changes to address alarm safety.	QI study with convenience sampling to understand nurses' perceptions of alarm fatigue and implement interventions that improve safety. Healthcare Technology Foundation's Clinical Alarms Committee Survey was sent to 31 nurses and 14 support staff (83.8% operational response rate).	Mary Lanning Healthcare (acute care facility). ICU and progressive care unit (29 beds total).		When surveyed about knowledge of Mary Lanning Healthcare's initiatives to improvement alarm fatigue, only 15% of nurses recognized that the alarm management team was implemented to assess current needs, edit policies, decrease overall alarm numbers, and change the culture of alarm management. Only 19% of nurses recognized that new technology had been implemented to improve clinical alarm safety.	Survey results illustrated a lack of knowledge and training in alarm management. Mary Lanning Healthcare implemented a variety of change initiatives based on assessment, current needs, nurse perception, and evidence-based practice.	Moderate	Included in PSP 1

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Rayo et al., 2016[10]	Alarms task force (physicians, nurses, subject matter experts in IT, human factors engineering, risk management, and data analysis) was formed in response to TJC NPSG. Task force was divided into subcommittees: executive steering, physiological monitoring oversight, platform, training and implementation, and monitoring and evaluation.	Retrospectively collected data from an institutional data warehouse for the 12-week periods before and after the intervention was implemented. Percentages of true, false, and unnecessary alarms were collected by conducting six 2-hour observations across three different units.	Midwest tertiary care health system. Intervention was implemented in 5 hospitals, affecting 37 medical-surgical, cardiac, critical care, and hybrid units (over 1,000 beds total).	False alarm percentage decreased from 18.8% to 9.6% pre- to post-intervention. Percentage of unnecessary alarms remained consistent between the pre- (46.2%) and post-intervention (46.7%) periods. When comparing hospital-wide data before and after implementation, average cardiac monitoring rate decreased 53.2%, weekly monitoring rate decreased 15.5%, and emergency department boarding rate decreased 36.6%.	Not provided	Results suggest that the development and communication of this new policy safely reduced the length of time that patients spent on continuous cardiac monitoring. Factors of successful implementation include strong leadership support and widespread engagement of staff. Human factors engineers worked closely with clinicians and IT professionals from the beginning, resulting in policy and technology solutions explicitly designed to optimize usability and mitigate the risk of increased workload and other unintended consequences sometimes associated with healthcare technology. Some subcommittees stayed intact after implementation to continue to monitor process/success of this and other alarm task force initiatives.	Moderate	Included in PSP 1

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Srinivasa et al. 2017[15]	Alarm Fatigue Group was formed to conduct a pilot study on the state of telemetry alarms on a surgical floor. The multidisciplinary team is made up of members representing nursing, biomedical engineers, patient safety, and providers.	QI study performed using two decision analysis models: fishbone analysis and Model for Improvement framework. Collected baseline and post-intervention alarm load and noise data.	Northeast healthcare facility, surgical telemetry unit (24 beds).	An 84% reduction in the premature ventricular contractions alarm rate, and a 54% reduction in the total alarm rate. There was also an overall noise reduction on the surgical telemetry unit related to the cardiac telemetry alarms. Pre-intervention the average noise in decibels (dB) for the left wing and main hallway was 58.94 dB and 58.04 dB, respectively. Post-intervention it dropped to 57.84 dB and 54.43 dB, respectively.	Not provided	Factors that contributed to the success of reducing alarm load and alarm fatigue: (1) Change was integrated into the unit with very little interruption in the flow of the unit. (2) Stakeholder involvement and buy-in from the start. (3) TJC Sentinel alert and subsequent establishment of NPSG on Alarm Management enabled vigorous administrative support and resources required to successfully lead this project.	Moderate	Included in PSP 1
Vockley, 2012[3]	Established telemetry task force that guides decisions around alarm system management. The multidisciplinary task force is made up of physicians, nurses, and clinical engineering, healthcare quality, facilities, and supply management staff.	Case study	Beth Israel Deaconess Medical Center (631 beds).	A 30% decrease in alarm signals. Decrease in amount of time it takes to respond to an alarm.	Not provided	Resulted in a culture of taking action around auditing the standard of care and patient outcomes, and continuing to adjust alarm system parameters to meet clinical practice standards.	High: case study and not peer reviewed	Pulled from AAMI Safety Innovations Series—manual search Included in PSP 1

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Whalen et al., 2014[7]	BMC senior leadership convened a multidisciplinary Telemetry Task Force (TTF) in 2008 to evaluate how cardiac telemetry monitoring equipment was being used in clinical areas, identify ways to improve management and utilization, and develop consensus for a common approach to cardiac monitoring. Reconvened the TTF in 2011 to explore the issue alarm fatigue.	Two-phase study: (1) observation of nursing staff's response to monitor alarms and (2) QI project in pilot unit to respond to largest contributors to alarm fatigue identified in Phase 1.	Boston Medical Center, medical cardiology unit (24 beds).	An 89% reduction in total number of audible alarms per week on pilot unit. Decibel level narrowed from a range of 54-90 dB to 60-72 dB. Percentage of nurses who assessed the noise level as acceptable increased from 0% to 64%.	Not provided	Success of QI study was the result of a multidisciplinary approach. Nurses became strong advocates of the pilot project, which resulted in sustained change and improvement.	Moderate	Included in PSP 1

Appendix C. Alarm Fatigue Search Terms

Method	Search	Search String for: CINAHL	Search String for: MEDLINE
Search 2008-Present, English Only MedLine Publication Types: • Clinical Trial • Clinical Trial, Phase I • Clinical Trial, Phase II • Clinical Trial, Phase III • Clinical Trial, Phase IV • Comparative Study • Controlled Clinical Trial • Corrected and Republished Article • Evaluation Studies • Guideline • Journal Article • Meta-Analysis • Multicenter Study	Safety Culture	(((MH "Organizational Efficiency" OR "Organizational Culture" OR "Health Care Errors") OR (AB "Safety Performance" OR "Safety Program" OR "Safety Culture" OR "Comprehensive Safety Program" OR "Safety Climate" OR "Leadership Walk Rounds" OR "Guideline" OR "Clinical Protocol" OR "Team Training")) AND (AB "Alarm Desensitization" OR (Alarm AND Desensitization) OR ("Clinical Alarm" AND Desensitization)))	(((MH "Efficiency, Organizational" OR "Organizational Culture" OR "Safety Management/OG" OR "Medical Errors" OR "Quality Improvement") OR (AB "Safety Performance" OR "Safety Program" OR "Safety Culture" OR "Comprehensive Safety Program" OR "Safety Climate" OR "Leadership Walk Rounds" OR "Guideline" OR "Clinical Protocol" OR "Team Training")) AND (AB "Alarm Desensitization" OR (Alarm AND Desensitization) OR ("Clinical Alarm" AND Desensitization)))

Method	Search	Search String for: CINAHL	Search String for: MEDLINE
• Practice Guideline • Published Erratum • Randomized Controlled Trial • Review • Scientific Integrity Review • Technical Report • Twin Study • Validation Studies CINAHL Publication Types: • Clinical Trial • Corrected Article • Journal Article • Meta-Analysis • Meta Synthesis • Practice Guidelines • Randomized Controlled Trial • Research Review • Systematic Review			

Method	Search	Search String for: CINAHL	Search String for: MEDLINE
Search 2008-Present, English Only MedLine Publication Types: • Clinical Trial • Clinical Trial, Phase I • Clinical Trial, Phase II • Clinical Trial, Phase III • Clinical Trial, Phase IV • Comparative Study • Controlled Clinical Trial • Corrected and Republished Article • Evaluation Studies • Guideline • Journal Article • Meta-Analysis • Multicenter Study	Alarm Risk Assessment	(((MH "Risk Assessment" OR "Multidisciplinary Care Team") OR (AB "Risk Assessment" OR "Assessment" OR "Monitor" OR "Comprehensive Unit-Based Safety Program" OR "Interdisciplinary" OR "Management Committee")) AND (AB "Alarm Desensitization" OR (Alarm AND Desensitization) OR ("Clinical Alarm" AND Desensitization))	(((MH "Risk Assessment" OR "Patient Care Team") OR (AB "Risk Assessment" OR "Assessment" OR "Monitor" OR "Comprehensive Unit-Based Safety Program" OR "Interdisciplinary" OR "Management Committee")) AND (AB "Alarm Desensitization" OR (Alarm AND Desensitization) OR ("Clinical Alarm" AND Desensitization))

Method	Search	Search String for: CINAHL	Search String for: MEDLINE
• Practice Guideline • Published Erratum • Randomized Controlled Trial • Review • Scientific Integrity Review • Technical Report • Twin Study • Validation Studies CINAHL Publication Types: • Clinical Trial • Corrected Article • Journal Article • Meta-Analysis • Meta Synthesis • Practice Guidelines • Randomized Controlled Trial • Research Review • Systematic Review			

Method	Search	Search String for: CINAHL	Search String for: MEDLINE

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