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Use of Pagers With an Alarm Escalation System to Reduce Cardiac Monitor Alarm Signals

Maria M. Cvach, DNP, RN, CCRN; Robert J. Frank, CET; Pete Doyle, PhD, CHFP; Zeina Khouri Stevens, PhD, RN

Alarm fatigue desensitizes nurses to alarm signals and presents potential for patient harm. This project describes an innovative method of communicating cardiac monitor alarms to pagers using an alarm escalation algorithm. This innovation was tested on 2 surgical progressive care units over a 6-month period. There was a significant decrease in mean frequency and duration of high-priority monitor alarms and improvement in nurses' perception of alarm response time, using this method of alarm communication. **Key words:** *alarm fatigue*, *clinical alarms*, *fatigue/prevention and control*, *medical errors/prevention*, *noise/adverse effects*, *pagers*

THE MYRIAD of medical device alarm signals has created an environment that poses significant risk to patient safety. Studies indicate that 80% to 99% of alarms generated by medical devices are false and/or clinically insignificant, resulting in a phenomenon known as *alarm fatigue*.[1-4] Alarm fatigue is a national problem and can lead to alarm desensitization, resulting in errors of inattention, distraction, or omission.[5] From 2005 to 2008, the Food and Drug Administration MAUDE: Manufacturer and User Facility Device Experience database received 566 reports of patient deaths related to monitoring device alarms.[6] ECRI Institute (formally known as the Emergency Care and Research Institute), a nonprofit organization that uses applied scientific research in health care to establish best practices for improving patient care, publishes an annual top-10 technology hazards list. Alarm hazards have been named the number 1 health technology device hazard for the past 2 years and have been in the top-10 list since its inception.[7]

Clinicians rely on alarm signals to notify them of impending problems. When too many alarms are false and/or clinically insignificant, staff may fail to respond to a true event. One of the major reasons for false alarms is high sensitivity in medical device alarm systems intended to prevent a missed true alarm event.[8] Although effort is underway to decrease the false alarm rate with technological advances, such as multiparameter algorithms (smart alarms) and signal filtering, these approaches are not widely available.[8]

Our challenge was to ensure adequate monitor alarm notification on units that have spacious designs, long hallways, private rooms, and multiple nursing stations. A new hospital construction project afforded us the opportunity to rethink our units alarm notification design and evidence-based ways to minimize alarm fatigue and maximize alarm response. Alternative approaches considered

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Author Affiliation: *The Johns Hopkins Hospital, Baltimore, Maryland.*

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Correspondence: *Maria M. Cvach, DNP, RN, CCRN, The Johns Hopkins Hospital, 600 N Wolfe St, Baltimore, MD 21287 (mcvach@jhmi.edu).*

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included monitor watchers and both fixed and portable secondary alarm notification devices.

REVIEW OF LITERATURE

Despite few studies supporting the benefit of human cardiac monitor watchers, this alarm management approach is prevalent in many hospitals today.[9] There is no randomized controlled research evidence indicating the benefit of this approach or how many monitors can be safely viewed by a single monitor watcher.[8] In addition, this alarm management strategy is costly, requiring about 4.5 full-time employees to continuously manage 32 to 60 patient waveforms. Our hospital uses only unit-based monitor watchers on 2 high-risk units. On all other units, nurses must remain attentive to alarm signals through a variety of methods using both primary and secondary alarm notification systems.

Research evidence indicates that the use of other technologies, such as pagers, may be a viable alternative to human monitor watchers, with no significant difference in patient outcomes.[10,11] There are several problems associated with pagers for alarm notification. One problem is that the paging device may fail to communicate alarm signals due to network or connectivity issues. Another problem is the lack of false alarm signal filtering. Monitor watchers filter clinically insignificant alarms otherwise automatically sent to pagers. Bonzheim et al[12] conducted a study of nurses' responses to telemetry alarm signals using a monitor watcher to communicate alarm information directly to the nurse's voice communication badge. Time to first contact from the monitor watcher to the nurse was significantly better with the voice communication badge than with a 1-way pager ($P < .0003$).[12] This approach offered the additional benefit of alarm filtering by the monitor watcher, thereby minimizing the number of false alarm signals sent to the nurse and closing the communication loop by allowing nurse acknowledgment on the notification device.

False alarms reduce the credibility of an alarm monitoring system, resulting in a cry wolf phenomenon whereby clinicians may ignore or respond slowly to a recurring alarm signal.[13] An approach to reduce false alarm signals is to reduce sensor (ie, electrodes, leads, probes) artifact induced by patient movement.[14] Studies indicate that staff manipulation of monitor sensors during patient care activities results in alarms that self-correct without any intervention.[3,15] False alarms could be reduced by suspending monitor alarms for a short time period prior to patient manipulations. In a study, adding a 14-second delay removed about 50% of ineffective alarm signals and adding a 19-second delay removed about 67% of ineffective alarm signals.[15] Suctioning, washing, repositioning, and oral care conducted during quiescent alarm states generated many false alarm signals.[15]

Another approach to reduce false alarm frequency is the use of smart alarm technology that applies multiparameter filters, threshold delays, fuzzy logic, and/or technical validation before alerting the clinician.[16-23] Evidence indicates that these new technologies result in fewer but better alarm signals by reducing the number of clinically insignificant alarms; however, they are not available in most monitoring systems today.

An approach that blends the use of a wireless device for alarm notification with preprogrammed delays and closed-loop communication is newly emerging as a viable option for alarm management. Alarm integration systems provide intelligence in routing alarm signals to mobile devices through predefined workflow algorithms.[24] The alarm integration system serves as a router to send signals sequentially to a specified person(s). The algorithms enable the use of customized filters, which result in transmission of fewer alarm signals and a reduction in false and/or clinically insignificant alarms. Such filters screen alarm conditions that self-correct or are caused by patient manipulation.

Our hospital uses an alarm integration system that routes alarm signals from multiple medical devices to mobile wireless devices and affords the ability to create alarm notification algorithms as an alternative to human monitor watchers. This quality improvement (QI) project involves an innovative approach to notify nurses of high-priority cardiac monitor alarm signals using an alarm escalation algorithm to selectively filter, delay, and route alarms to appropriate caregivers' acknowledgement pagers.

METHODS

Aims of the project

The purpose of this project was to determine whether a cardiac monitor alarm escalation algorithm that filters physiologic monitor alarms before sending them to a nurse's acknowledgement pager is an effective method to notify staff of high-priority alarm signals. There were 2 specific aims: (1) to decrease the average frequency and duration of high-priority cardiac monitor alarms per monitored bed and (2) to improve nurses' attitudes about clinical alarms, including perception of effectiveness of notification devices.

Unit descriptions

This QI project took place at The Johns Hopkins Hospital, after approval by our hospital's institutional review board, on 2 surgical progressive care units from April 2012 to October 2012. The hospital was in the midst of a large renovation project, and both 28-bed units moved from their original location to spacious 32-bed units in a new building. Unit A specializes in cardiac surgical procedures, including cardiac transplantation; unit B specializes in noncardiac surgical procedures, including noncardiac organ transplantation. Most patients on unit A are monitored until hospital discharge (average monitor census 25), whereas unit B typically has fewer monitored patients (average monitor census 4). The patient-to-nurse ratio on both units is 3:1 on day shift and 4 to 5:1 on evening and night shifts. The new units are identical in size and configuration, have only private rooms, and have multiple nursing stations. Primary cardiac monitor alarm notification is provided by the patient's bedside monitor as well as central cardiac monitors located at the nursing stations. The units do not have centralized or unit-based human monitor watchers. Before moving to their new location, both units relied on hearing alarm signals from the bedside or central monitor without the use of a wireless communication device. Alarm audibility is a particular challenge in the spacious new units, so reliable secondary alarm notification was necessary to ensure prompt cardiac monitor alarm response when the nurse was not in proximity of the primary alert systems.

The innovation: Alarm escalation algorithm and acknowledgement pager for alarm notification

The Johns Hopkins Hospital Alarm Committee developed an alarm escalation algorithm for crisis and noncrisis cardiac monitor alarm conditions. This algorithm (Figure 1) was designed by examining alarm logs and determining which high-priority cardiac monitor alarms were actionable and should be sent to the nurses' alarm notification pager. The pager functions on a dedicated, radio-based network and receives cardiac monitor alarm signals sent through the alarm integration system. The acknowledgement function allows the user to confirm receipt of a page to close the communication loop. Both units use the same cardiac monitors and have the same monitor alarm default parameters. Nurses follow the hospital's Cardiac and Physiologic Monitor policy, which allows patient-specific alarm customization by the nurse.

Actionable, high-priority alarms were divided into crisis and noncrisis conditions. Crisis alarm conditions are sent immediately to the nurse's acknowledgement pager following an alarm escalation path across a predetermined sequence (Figure 1); noncrisis, high-priority alarm conditions are sent to the nurse's acknowledgement pager only if the alarm persists longer than 60 seconds. This time frame was selected by examining the units' alarm duration logs, which indicated that approximately 90% of alarm conditions self-correct in less than 60 seconds. We anticipated that sending noncrisis alarms to a care provider before 60 seconds would result

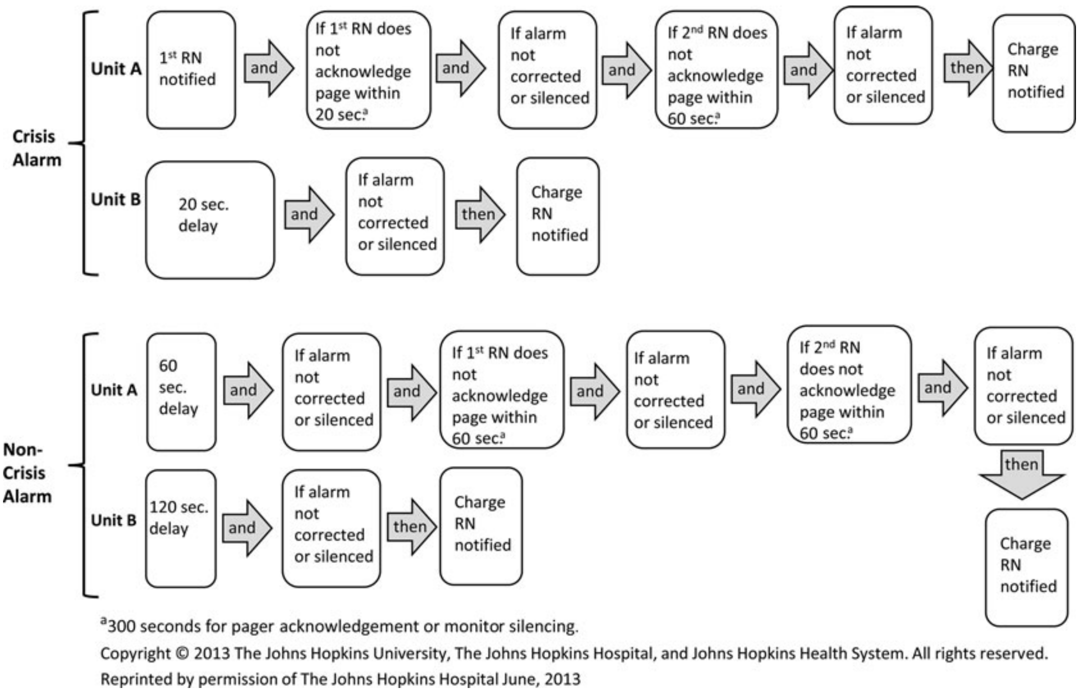

Figure 1. Alarm escalation algorithm.

in too many clinically insignificant "nuisance" alarms, thereby desensitizing staff. The Alarm Committee agreed that noncrisis alarm conditions that persist for longer than 60 seconds require intervention and should be communicated to the nurse's pager. Once the nurses receive alarm notification, they could either acknowledge receipt on the pager, allowing a predefined period of time for alarm correction prior to subsequent escalation to other staff, or immediately escalate the alarm signal by pressing an escalation button. In that case, the alarm signal is immediately routed to the backup care provider. If the alarm persists after escalation for a predefined time, it is sent to the charge nurse's pager as the final escalation step.

Unit A implemented this process by providing an acknowledgement pager to each nurse who was responsible for responding to the patient's alarm signals. For each shift, primary and secondary alarm escalation assignments were made using an alarm integration system. Because monitor census is low in unit B, they decided to provide an acknowledgement pager only to the charge nurse who was responsible for responding to all alarm signals and serving the backup role. The units began using the new process on April 2012 after their move.

Measurement of alarm frequency and duration

Using the alarm integration system, clinical engineering captured de-identified monitor alarm data from both units for 3 predetermined, 7-day time frames. The data retrieved included bed number, name of alarm, duration, date, time, and alarm priority. Data were collected at T_0 (baseline, prior to the units moving and before implementation of the alarm escalation algorithm); T_1 (2 months after the units moved and postimplementation of the alarm escalation algorithm); and T_2 (4 months postimplementation of the alarm escalation algorithm). Data were provided to the investigators in a spreadsheet format.

Alarms were sorted into the following categories: (1) patient status alarms included high-priority (crisis), medium-priority (warning), and low-priority (advisory) signals; and (2) technical alarms including lead and telemetry battery failure. Since low-priority monitor alarms occur frequently, are available for review in alarm data logs, and generally do not require immediate attention, these alarm signals were not incorporated into the alarm escalation algorithm. Only alarms defined a priori as high priority (crisis, warning, and select technical alarms) were included in the alarm escalation algorithm (Figure 1). Monitor census was acquired for each day studied, allowing calculation of alarms per monitored bed. Alarm data were transferred into IBM SPSS Statistics for Windows (version 20; Armonk, New York)[25] for calculation of selected outcomes, which included mean alarm frequency and duration per monitored bed.

Measurement of nurses' perception of alarms

A 2011 Clinical Alarms Survey, previously used for national online alarm surveys, was selected for measuring nurses' perception of alarms. The tool was developed in 2005 by the American College of Clinical Engineering Healthcare Technology Foundation as a way to identify alarm design issues, opportunities for enhancements, perception of alarm response, and appropriate actions to resolve alarm-related issues.[26] It consists of a 22-item instrument for clinicians to rate their opinions on a Likert scale (1 = strongly agree; 5 = strongly disagree). In addition, there are 9 alarm issues that participants are asked to rank order (1 = most important; 9 = least important). Validity or reliability data were not available from the survey developer; however, we calculated internal consistency on our survey data using the Cronbach α, which yielded a coefficient of 0.75 (pretest) and 0.78 (posttest). Seven survey questions were selected a priori based on prediction of how the alarm escalation algorithm may affect nurses' perceptions of alarms (see Supplemental Digital Content, Table, available at: http://links.lww.com/JNCQ/A32).

Of the 24 RNs who took the preintervention survey and the 31 RNs who took the postintervention survey, 15 RNs could be matched by personal identification number and/or demographics. Demographic data for the 15 nurses indicated that the respondents were predominantly full-time, bachelor of science in nursing–prepared females with 3 or more years of experience working on a cardiac monitored unit.

RESULTS

Aim 1: Frequency and duration of alarm signals

Average alarm frequency and duration per monitored bed per day were measured at 3 predetermined time intervals (T_0, T_1, and T_2). There were 14 312 high-priority cardiac monitor alarm signals from both units ($T_0 = 5134$ alarms; $T_1 = 3172$ alarms; $T_2 = 6006$ alarms) occurring during the 3 (7-day) assessment intervals, with 89% of the alarms occurring on unit A, which had a higher monitor census than unit B. A total of 868 of these alarm signals were removed from data analysis. The removed alarms included 583 alarm signals that were deemed as artifacts due to a duration of less than 1 second and 285 alarm signals that had a duration exceeding 600 seconds, the maximum duration of the alarm escalation algorithm. Of the 285 alarm signals exceeding 600 seconds, 274 (96%) were technical alarms (eg, leads fail, arrhythmia suspend).

Results for average alarm frequency per monitored bed per day are presented in Figures 2 (unit A) and 3 (unit B). A linear regression line demonstrates that the slope of the trend line decreased by 0.75 alarms per bed per day when nurses carried an acknowledgement pager and received their own patients' monitor alarms. Unit B demonstrated a slight increase in alarms per bed per day with the slope of the trend line, increasing 0.07

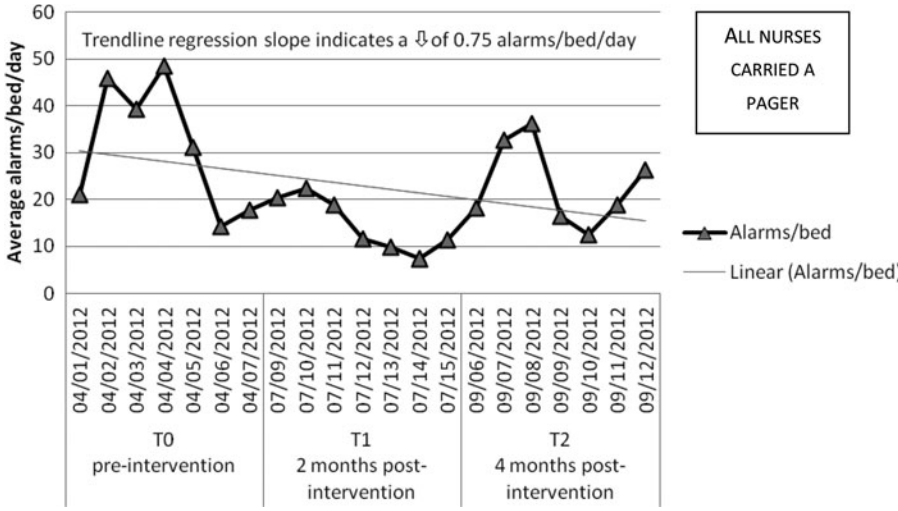

Figure 2. Unit A: Average alarms per bed per day.

alarms per bed per day when only the charge nurse carried the acknowledgement pager.

Figures 4 and 5 demonstrate the decrease in average alarm duration per day for both units. Unit A exhibited a larger decrease than unit B. A linear regression line demonstrates that for every day, the slope of the trend line decreased by 0.33 seconds per day for unit A and 0.27 seconds per day for unit B. The difference in mean alarm duration time from T_0 to T_2 was 5.19 seconds for unit A and 2.27 seconds for unit B.

Aim 2: Nurses' perception of alarms

A paired-samples t test was conducted to evaluate the impact of the intervention on perception of alarms. There was a statistically significant change in perception of nurse

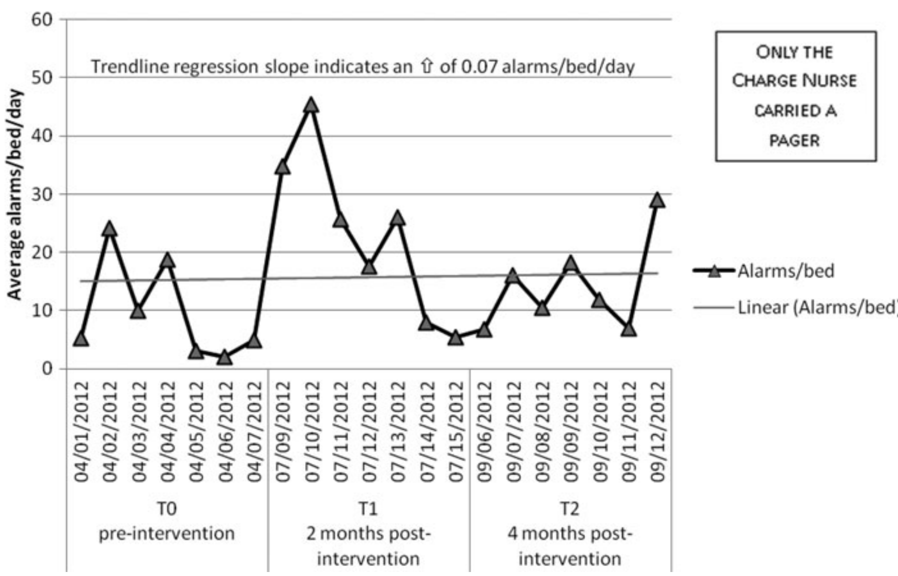

Figure 3. Unit B: Average alarms per bed per day.

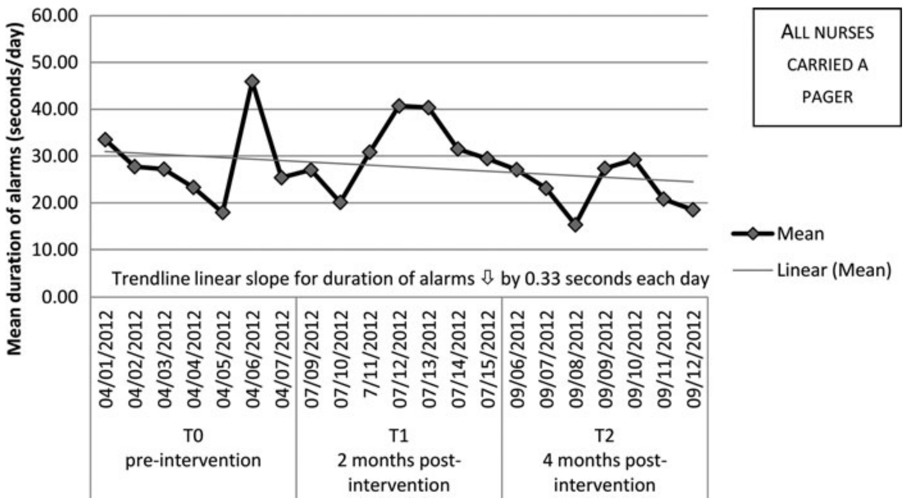

Figure 4. Unit A: Mean duration of alarms.

sensitivity to alarms and quickness of response (Q13) from preintervention (M = 2.73, SD = 0.88) to postintervention (M = 2.13, SD 0.83), $P = .045$ (2-tailed). The mean change in perception was 0.6 (SD = 1.1), with 95% confidence interval ranging from 0.02 to 1.18. The η^2 statistic (0.26) indicated a large effect size. Although there was change in a positive direction in nurses' perception of adequacy of alarms to alert staff (Q11) and their perception of the benefit of alarm integration tools (Q18), the results were not statistically significant.

To compare our data with that which was obtained during a national survey,[9] we combined "agreed" and "strongly agreed" responses for the 7 alarm survey questions shown in the Supplemental Digital Content Table (available at http://links.lww.com/JNCQ/A32). The responses for paired groups'

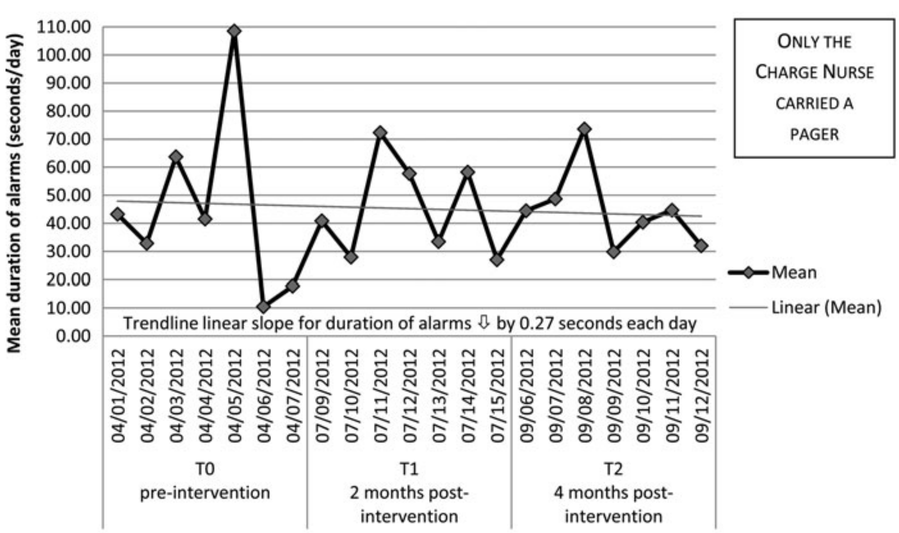

Figure 5. Unit B: Mean duration of alarms.

pre-/postimplementation of the alarm escalation algorithm demonstrate improvement in nurses' perception of alarm adequacy in alerting staff to changes in patient conditions (Q11), staff sensitivity and response to alarms (Q13), and usefulness of alarm integration systems via pager in improving alarm response (Q18). There was no change in nurses' perceived frequency of nuisance alarms (Q5), perceived propensity to turn nuisance alarm signals off (Q7), or perceived difference in the number of missed alarms (Q12). There was an increase in nurses' perception that nuisance alarms disrupt patient care (Q6). Our postintervention results were comparable with the responses from the national sample, except that our results showed a greater perception that alarm integration is useful in improving alarm management/response (Q18).

DISCUSSION

Summary of outcomes

Our results indicate that the alarm escalation algorithm and acknowledgement pager improved nurse notification of high-priority monitor alarms on surgical progressive care units. The frequency and duration effects were more pronounced on unit A, where each nurse carried a pager and received his or her own patient's alarm signals. There was a slight increase in the average frequency of alarms per monitored bed per day on unit B, where only the charge nurse carried a pager (Figures 2 and 3); however, there was a decrease in mean alarm duration. Overall, it took unit B longer to respond to alarms, as evidenced by the longer mean alarm duration than unit A (Figures 4 and 5), despite having fewer patients on cardiac monitors. This is understandable, given that each RN on unit B did not receive personal notification for his or her monitored patient's alarms.

The clinical alarm survey results indicate improved perception of nurse sensitivity and responsiveness to alarm signals postintervention; however, nuisance alarms were still perceived as being disruptive to patient care. The additional notification provided by pagers may have been perceived as a nuisance since the nurse may have received 2 alarms for the same event: primary (from the bedside monitor) and secondary (from the pager). It is difficult to know whether the intervention was the reason for the change in nurses' perception to sensitivity and responsiveness to alarm signals. Both units experienced substantial change as a result of moving into new units, and this may have had an effect on nurses' responses.

Implications

The implications of this QI project are noteworthy. This is the first publication to demonstrate the use of an alarm integration system and an acknowledgment pager for secondary alarm notification. Adding a delay to noncrisis alarm signals, before sending the signal to a secondary alarm notification device, allows time for the primary alarm signal to correct. Delays minimize the amount of alarm signals sent to the nurse's pager, thereby decreasing distraction and increasing the likelihood that alarm signals sent to the nurse's pager are actionable.

Recommendations for further investigation

This project did not investigate false alarm prevalence. Studies are needed to determine the effect of the alarm escalation algorithm on the false alarm rate. This project took place on units that had both bedside and central monitors. Results may differ on units without the necessary equipment to enable viewing and correction of alarm signals at the patient's bedside. More work is needed to determine whether an alarm escalation algorithm and an acknowledgement pager are viable options for units that do not have bedside or central monitors.

The acknowledgement pagers used in this project did not provide a waveform display. A waveform display would have provided context to the alarm text message. It is uncertain whether this would have improved the project results by enabling the nurse to make decisions regarding the need to take action. Having a waveform display may have discouraged nurses from going to the patient's bedside or central monitor to validate the alarm signal. More work is needed to test the benefit of using an alarm escalation algorithm along with an acknowledgement pager with a waveform display.

Limitations

Quality improvement data limit generalization of results. In addition, the following limitations related to the 2 study aims should be considered: First, by moving to more spacious units, the duration of alarms may have been affected. The time to resolve alarm conditions was impacted by greater distances that staff had to walk to correct alarm signals. In addition, there were fewer monitored patients on unit B, resulting in fewer alarm signals for calculation of average frequency/duration than on unit A.

Second, the sample size of 15 was insufficient for testing significance of nurses' perception of alarms. In addition, the alarm notification process differed in that each nurse carried a pager on unit A whereas only the charge nurse carried a pager on unit B. A confounding factor that may have influenced nurses' responses to the alarm survey was the addition of a wireless phone to communicate nurse call system messages/alerts on both units after their move, increasing the number of alarm signals communicated to the nurse (eg, bed exit, ventilator, bathroom calls) and resulting in nurses on unit A having to carry 2 different alarm notification devices (ie, a phone and a pager).

CONCLUSIONS

The desired outcomes, decreased mean alarm frequency and duration, were achieved when each nurse carried a pager (unit A) and received direct alarm notification for his or her patients. We conclude that the combination of an alarm escalation algorithm and an acknowledgement pager has potential to improve alarm response time and minimize alarm fatigue by decreasing nonactionable alarm signals sent to the nurse. A decrease in alarm signals results in less noise at the patient's bedside and improved nurse awareness of relevant alarms. For units without monitor watchers, this may be a viable option to ensure secondary alarm notification.

REFERENCES

1. Lawless ST. Crying wolf: false alarms in a pediatric intensive care unit. *Crit Care Med*. 1994;22(6):981-985.
2. Tsien C, Fackler J. Poor prognosis of existing monitors in the intensive care unit. *Crit Care Med.* 1997;25(4):614-619.
3. Chambrin MC, Ravaux P, Calvelo-Aros D, Jaborska A, Chopin C, Boniface B. Multicentric study of monitoring alarms in the adult intensive care unit (ICU): a descriptive analysis. *Intensive Care Med*. 1999;25(12):1360-1366.
4. Atzema C, Schull MJ. Alarmed: adverse events in low-risk patients with chest pain receiving electrocardiographic monitoring in the emergency department: a pilot study. *Am J Emerg Med.* 2006;24(1):62-67.
5. ACCE Health Technology Foundation. Impact of clinical alarms on patient safety. A report from the American College of Clinical Engineering Healthcare Technology Foundation. *J Clin Eng.* 2007;32(1):22-33.
6. US Food and Drug Administration. *FDA Patient Safety News: Alarm Monitoring Problems*. Silver Spring, MD: US Food and Drug Administration; 2011. http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/psn/transcript.cfm?show=106#7. Accessed July 27, 2011.
7. ECRI Institute. Top 10 health technology hazards for 2013. https://www.ecri.org/Documents/Secure/Health_Devices_Top_10_Hazards_2013.pdf. Accessed January 1, 2013.
8. Cvach M. Monitor alarm fatigue: an integrative review. *Biomed Instrum Technol*. 2012;46(4):268-277.
9. Healthcare Technology Foundation. National clinical alarms summary: perceptions, issues, improvements, and priorities of healthcare professionals. Paper presented at: the Medical Device Alarm Summit; October 4-5, 2011; Herndon, VA.
10. Funk M, Parkosewich JA, Johnson CR, Stukshis I. Effects of dedicated monitor watchers on patients' outcomes. *Am J Crit Care*. 1997;6(4):318-323.

11. Zweig F, Karfonta T, Jeske L, Kollauf C, White S, Drazewski R, Leske J. Arrhythmia detection and response in a monitoring technician and pocket paging system. *Prog Cardiovasc Nurs*. 1998;13(1):16-22, 33.
12. Bonzheim K, Gebara R, O'Hare B, et al. Haines D. Communication strategies and timeliness of response too life critical telemetry alarms. *Telemed J E Health*. 2011;17(4):241-246.
13. Sendelbach S. Alarm fatigue. *Nurs Clin N Am*. 2012; 47:375-382.
14. Cvach MM, Biggs M, Rothwell KJ, Charles-Hudson C. Daily electrode change and effect on cardiac monitor alarms. *J Nurs Care Qual*. 2013;28(3):265-271.
15. Gorges M, Markewitz BA, Westenskow DR. Improving alarm performance in the medical intensive care unit using delays and clinical context. *Anesth Analg.* 2009;108(5):1546-1552.
16. Biot L, Holzapfel L, Becq G, Melot C, Beconnier P. Do we need a systematic activation of alarm soundings for blood pressure monitoring for the safety of ICU patients? *J Crit Care Nurs.* 2003;18(4): 212-216.
17. Blum JM, Kruger GH, Sanders KL, Gutierrez J, Rosenberg AL. Specificity improvement for network distributed physiologic alarms based on a simple deterministic reactive intelligent agent in the critical care environment. *J Clin Monit Comput*. 2009;23(1): 21-30.
18. Borowski M, Siebig S, Wrede C, Imhoff M. Reducing false alarms of intensive care online-monitoring systems: an evaluation of two signal extraction algorithms. *Comput Math Methods Med.* 2011; 2011:143480. doi:10.1155/2011/143480.
19. Burgess LPA, Herdman TH, Berg BW, Feaster WW, Hebsur S. Alarm limit settings for early warning systems to identify at-risk patients. *J Adv Nurs*. 2009;65(9):1844-1852.
20. Gross B, Dahl D, Nielsen L. Physiologic monitoring alarm load on medical/surgical floors of a community hospital.*Biomed Instrum Technol.* 2011;(suppl): 29-36.
21. King A, Roderer A, Arney D, et al. GSA: A framework for rapid prototyping of smart alarm systems. Paper presented at: Proceedings of the 1st ACM International Health Informatics Symposium; November 11-12, 2010; Arlington, VA.
22. Otero A, Felix P, Barro S, Palacios F. Addressing the flaws of current critical alarms: a fuzzy constraint satisfaction approach. *Artif Intell Med*. 2009;47(3):219-238.
23. Schmid F, Goepfert MS, Kuhnt D, et al. The wolf is crying in the operating room: patient monitor and anesthesia workstation alarming patterns during cardiac surgery. *Anesth Analg*. 2011;112(1):78-83.
24. Hoglund D, Elms J. The use of mobile devices to improve alarm systems. *Biomed Instrum Technol.* 2011;(suppl):381-384.
25. IBM Corp. *Released 2011. IBM SPSS Statistics for Windows*. Version 20.0. Armonk, NY: IBM Corp.
26. Clark T. Is the warning effective? Clinical alarms remain area for patient safety improvement. *Biomed Instrum Technol*. 2005;39(5):357-358.