The Art and Science of Infusion Nursing

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Perceptions of Infusion Pump Alarms

Insights Gained From Critical Care Nurses

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ABSTRACT

Between 1983 and 2011, equipment-related alarms in critical care have increased from 6 to 40 different alarm types. As nurses become overwhelmed, distracted, or desensitized by alarm noise, they may miss critical alarms that could result in patient harm. The findings of an infusion pump alarm survey indicated that nurses overwhelmingly agree that infusion pump nuisance alarms occur frequently and disrupt patient care. But nurses' perceptions of pump alarms are different from those previously reported for clinical alarms in general. It may not be appropriate to broadly apply general alarm management recommendations to infusion pump alarms at this time.

Key words: alarm fatigue, alarm survey, clinical alarms, critical care nurses, false alarms, infusion pump alarms, nonactionable alarms, nuisance alarms, nurse alarm perceptions

The hospital environment is replete with equipment-related clinical alarms that are intended to alert nurses regarding the condition of their patients. Unfortunately, there are so many alarms that these sounds, combined with other environmental noises, result in noise pollution.[1] For the patient, noise can disrupt sleep and circadian rhythms, causing increased delirium and length of stay.[1] To optimize healing and reduce the risk of disease, the World Health Organization (WHO) recommends that hospital sound levels should not exceed 30 decibels (dB) (eg, a soft whisper) for continuous sound and 40 dB (eg, a quiet library) for maximum sound.[1,2] However, sound levels in hospitals and patient rooms can surpass these recommendations, as levels have been measured between 43 dB (eg, the sound of birdcalls) at night and as high as 85 dB (eg, a food blender) throughout the day.[1,3-5] It is important to note that these hospital sound recommendations date from 1999,[2] at which time there were approximately 6 types of alarms in a critically ill patient's room.[6] By 2011, there could be as many as 40 types of alarms in a patient's room, despite research to suggest that nurses have difficulty differentiating between more than 6 distinct alarm sounds.[6]

From the nurse's standpoint, when alarms are perceived as legitimate and clinically actionable, they have the potential to improve patient care. But the high incidence of clinically nonactionable alarms, also referred to as false, nuisance, and clinically insignificant alarms, can distract from patient care; reduce nurses' trust in alarms; and lead nurses to ignore, silence, or respond more slowly to them.[7-9] It is the accumulation of this alarm noise pollution that has led to a lack of response to alarms due to sensory overload and desensitization or alarm fatigue.[10] Alarm fatigue in the hospital environment is now recognized as a serious issue because of its impact on caregivers and patients, with the potential to result in delays in treatment, serious injury, and death.[11] As such, the ECRI Institute, formerly the

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Emergency Care Research Institute, listed alarms, in general, as the number 1 technology hazard for 2014.[12] In its top 10 health technology hazards for 2017, ECRI more specifically stated that desensitization of staff to alarm activity in general could result in missed ventilator alarms, which could be deadly.[13] The Joint Commission (TJC) added alarm safety to its National Patient Safety Goals in 2014.[14] Making improvements to ensure that medical equipment alarms are heard and responded to in a timely manner continues to be a top patient safety goal of TJC in 2017.[15]

To explore alarm fatigue in clinicians, the Healthcare Technology Foundation (HTF) Clinical Alarms Committee developed an online survey to measure health care providers' perceptions of clinical alarms.[16,17] Health care organizations such as the American Association of Respiratory Care, American Association of Critical-Care Nurses (AACN), American College of Clinical Engineering, Association for the Advancement of Medical Instrumentation (AAMI), ECRI Institute, and the Medical Equipment and Technology Association supported the study by making members, subscribers, and other stakeholders aware of the survey. A link was posted on the HTF website and on the websites of the other organizations. The survey was first administered via SurveyMonkey (San Mateo, CA) in 2005 to 2006 and completed by 1327 respondents, including registered nurses, respiratory therapists, clinical engineers, biomedical equipment technicians, and clinical managers. The survey was modified slightly and then repeated in 2011 and completed by 4278 respondents.[18,19] In addition to demographic questions, the survey consisted of 5-point Likert-type statements about clinical alarms (22 questions in the 2006 survey; 20 questions in the 2011 survey), 9 ranking items regarding issues that inhibit clinical alarm management, and a request to comment on what is needed to improve clinical alarm recognition and response. No validity or reliability data were reported for either HTF survey.

Subsequently, 2 other quality improvement studies have used adapted versions of the HTF 2011 survey to look at the perceived burden of clinical alarms on smaller samples of caregivers.[20,21] Sowan et al,[20] referred to as TCICU 2015, adapted the HTF survey to use as a tool to better understand the attitudes and practices related to clinical alarms of 39 full- and part-time nurses (100% of the staff) working on a 20-bed transplant/cardiac intensive care unit (TCICU) with a nurse-to-patient ratio of 1:2. The survey was designed using SurveyMonkey and placed on the hospital's website. Before its use, it was reviewed for face validity by 4 intensive care unit (ICU) nurses. More recently, Petersen and Costanzo,[21] referred to as CCN 2017, used convenience sampling to gather responses from 26 of 31 critical care nurses (CCNs) who worked on an ICU and a progressive care unit with nurse-to-patient ratios of 1:2 and 1:4, respectively. The survey was completed electronically, and no validity or reliability measurements were reported.

All 4 surveys[16,19-21] have looked at perceptions related to clinical alarms in general, which included physiological monitors (cardiac monitors, pulmonary artery catheter monitoring, and pulse oximeters), mechanical ventilators, and infusion pumps. Most physiological monitor alarms (86%-99%) are clinically nonactionable because they automatically stop and reset when the patient-specific parameters return to within normal range.[10,22] These devices are set for high sensitivity; thus, compared with ventilators and infusion pumps, they have a higher incidence of alarms. Infusion pump alarms tend to sound continuously and cause an interruption to the therapy until the alarm condition is assessed and addressed by the nurse. Given the wide variability of cause and effect of alarms that are possible from the total population of medical devices, it may be more appropriate to investigate alarm perception results and improvement recommendations for each specific classification of device. With this in mind, the authors developed and used an infusion pump-specific adaption of the HTF 2011 clinical alarm survey (Appendix) to measure nurse perceptions related to infusion pump alarms and then compared the results with those reported by studies that measured clinical alarms in general.

METHODOLOGY

Study Objectives

The primary aim of this study was to measure nurse perceptions specifically related to infusion pump alarms. The secondary aim was to compare the new data with data previously collected on clinical alarms in general[19-21] to determine whether there are differences. The convenience sample consisted of nurses attending the May 2016 AACN National Teaching Institute (NTI) in New Orleans.

Study Design

After using an infusion pump-specific adapted version of the HTF 2011 survey to collect self-reported information on perceptions of infusion pump alarms, an initial exploratory descriptive analysis was conducted. The results then were used as part of a secondary analysis, which consisted of comparing this study's data against cross-sectional information extracted from 3 previous and public surveys (HTF 2011, TCICU 2015, and CCN 2017).[18-21]

Survey Development

An infusion pump-specific adapted version of the HTF 2011 clinical alarm survey[18,19] was created to collect data (Appendix). Permission was granted by HTF to adapt its survey, and a data use policy was acknowledged. Compared with HTF's surveys, the infusion pump-adapted version is briefer: 10 general statements as opposed to 20 to 22, and 5 ranking issues as opposed to 9. Questions that could not be appropriately applied to infusion pumps were removed, and in questions that could be applied to infusion pumps, the intent was maintained, but the wording was modified slightly so that it clearly pertained to infusion pumps only (Questions 1-7). Questions 8 to 10 were added based on narrative results from Sowan et al[20] and HTF[18]; unit layout

was perceived as interfering with alarm recognition and response, and central alarm management, monitoring personnel, and the integration of alarms with communication systems were perceived as helpful.[18,20] Of HTF's 9 ranking issues, only those that ranked in the top 5 from the results of the Sowan and HTF surveys were included in the AACN pump-specific survey. The adapted version was created by a study investigator and reviewed for clarity, applicability to the study population, and relevant demographics by 4 infusion therapy clinical specialists and an individual with expertise in electronic survey development and research. The AACN pump-specific survey consisted of 7 demographic questions, 10 5-point Likert scale general statements regarding infusion pump alarms which prompted respondents to rate their level of agreement from *strongly agree* to *strongly disagree*, and 5 issues to rank.

Data Collection and Analysis

Surveys were completed with paper and pencil, using optical mark recognition scan forms (Remark Office OMR; Gravic, Inc, Malvern, PA). All surveys were administered and collected at the AACN NTI conference by 3 study investigators. Participants included nurses attending alarm and non–alarm-related presentations at an infusion pump exhibitor booth and nurses who had visited the same infusion pump booth—approximately 80%, 10%, 10% of respondents, respectively. Surveys were anonymous, and there were no incentives offered to participate or penalties for nonparticipation. IBM SPSS Statistics 22.0 (IBM; Armonk, New York) was used to run descriptive statistics.

RESULTS

Two hundred five nurses completed the AACN infusion pump alarm survey. Ninety-one percent were female, average age was 45 years, average number of years in nursing was 19, and 73% worked in an ICU (Table 1). Because demographic data for the 3 comparison surveys were limited, it was not possible to assess the similarities or differences in the survey populations. Cronbach's alpha reliability for the 10 pump alarm perception questions was 0.75. Nurses agreed that pump nuisance alarms disrupt patient care (91%), followed by pump nuisance alarms occur frequently (87%), unit monitors with visual display of pump alarms would be useful (85%), and pump nuisance alarms reduce trust in alarms (83%). Nurses least agreed that staff are sensitive to pump alarms and respond quickly (47%). See Table 2 for data on strength of agreement on the pump alarm survey's statements.

When comparing the agreement strength of infusion pump alarm perceptions of AACN nurses versus the survey results of the 3 general device surveys, there seems to be a meaningful response variability (Table 3). While most AACN nurses agreed that pump nuisance alarms disrupt patient care, HTF 2011 survey respondents believed this is less of an issue (91% vs 71%). Similarly, nuisance alarms occurring frequently appears

TABLE 1

Demographic Description of Sample (N = 205)

Variable	Number (n)	Percentage (%)[a]
Gender (n = 204)		
Female	187	91
Male	17	8
Age (years) (n = 184)		
<30	20	38
31-40	59	32
41-50	38	21
51-60	49	27
>60	18	10
Average: 45		
Years in nursing (n = 194)		
<6	22	11
6-10	44	23
11-15	25	13
16-20	25	13
21-25	20	10
26-30	20	10
31-35	12	6
>35	26	13
Average: 19		
Hours worked (n = 197)		
Full-time	178	90
Part-time	19	10
Type of unit (n = 204)		
ICU	148	73
PICU	7	3
ED	5	2
Telemetry	23	11
Other	21	10
Job title (n = 200)		
Staff nurse	149	75
CNS/educator	22	11
Manager/supervisor	21	11
Other	8	4
Pump use (n = 196)		
Every workday	174	89
Occasionally	13	7
Rarely	9	5

Abbreviations: CNS, clinical nurse specialist; ED, emergency department; ICU, intensive care unit; PICU, pediatric intensive care unit.
[a]Values are rounded to nearest whole number.

TABLE 2

AACN Perceptions of Infusion Pump Alarms Survey Data (N = 205)

Statement	Strongly Agree		Agree		Neutral		Disagree		Strongly Disagree	
	n	%	n	%	n	%	n	%	n	%
Pump nuisance alarms disrupt patient care. (n = 205)	90	43.9	96	46.8	13	6.3	5	2.4	1	0.5
Pump nuisance alarms reduce trust in alarms and cause staff to silence alarms inappropriately at times other than setup or procedural events. (n = 203)	75	36.9	93	45.8	17	8.4	17	8.4	1	0.5
Pump nuisance alarms occur frequently. (n = 203)	91	44.8	86	42.4	15	7.4	10	4.9	1	0.5
Unit size or layout interferes with pump alarm recognition and management. (n = 201)	51	25.4	97	48.3	30	14.9	20	10.0	3	1.5
When a number of pumps are used on a patient, it can be confusing to determine which is sounding the alarm. (n = 202)	42	20.8	77	38.1	34	16.8	40	19.8	9	4.5
Alarm integration with communication systems (pagers, cell phones, other) would be useful for improving alarm recognition and management. (n = 203)	68	33.5	83	40.9	29	14.3	17	8.4	6	3.0
Unit noise (phones, pages, sounds of other devices) interferes with pump alarm recognition. (n = 203)	48	23.6	87	42.9	31	15.3	32	15.8	5	2.5
Staff are sensitive to pump alarms and respond quickly. (n = 204)	21	10.3	75	36.8	63	30.9	40	19.6	5	2.5
There have been frequent instances when pump alarms could not be heard and were missed. (n = 204)	52	25.5	89	43.6	28	13.7	29	14.2	6	2.9
Unit monitors with visual display of pump alarms (infusion, type of alarm, location) would be useful for improving alarm recognition and management. (n = 202)	78	38.6	93	46.0	24	11.9	6	3.0	1	0.5

Abbreviation: AACN, American Association of Critical-Care Nurses.

to be less of an issue for HTF 2011 (77%) versus AACN survey respondents (87%). While CCN 2017 (100%) and TCICU 2015 (98%) survey results indicated that nuisance alarms reduced trust in alarms, fewer AACN nurses (83%) thought this would cause staff to inappropriately silence alarms. The survey responses pertaining to staff sensitivity and response time for alarms indicated meaningful differences, with HTF 2011 survey responses 29% higher (66%) and TCICU 2015 survey responses 38% lower (34%) than the AACN survey result of 47%. The most profound variation in survey results was related to instances when alarms cannot be heard and are missed. AACN nurse responses were 97% to 137% higher (69%) for infusion pumps specifically, as opposed to more general alarm perceptions reported in the CCN 2017 (35%), TCICU 2015 (32%), and HTF 2011 (29%) surveys.

When AACN nurses were asked to rank 5 infusion pump alarm-related issues from 1 (most important) to 5 (least important), the mean rankings ranged from 2.26 to 2.86 (Table 4). *Frequent false alarms leading to reduced attention or response* was the most important issue (2.26), followed by *difficulty in identifying source of alarm* (2.69). Again, there was variation in the rankings of reported alarm-related issues when comparing the AACN survey with the CCN 2017, TCICU 2015, and HTF 2011 survey results. AACN and HTF 2011 nurses both ranked *frequent false alarms leading to reduced attention or response* the number 1 issue, while the CCN 2017 and TCICU 2015 surveys ranked it fourth. While *inadequate staff to respond to alarms as they occur* was the number 1 issue for CCN 2017 nurses, it ranked fourth for AACN nurses, and fifth for both TCICU 2015 and HTF 2011 respondents. Similar response variability was reported regarding *difficulty understanding the priority of an alarm*, with CCN 2017 and TCICU 2015 nurses ranking it the second most important issue. HTF 2011 and AACN survey respondents ranked it the third and fifth most important issue, respectively.

DISCUSSION

This study was a preliminary attempt to measure nurses' perceptions related to infusion pump alarms and compare

TABLE 3

Comparison of Agreement Strength of Alarm Perceptions[a]

Statement	AACN			CCN 2017[b]			TCICU 2015[c]			HTF 2011[d]		
	N	n	%	N	n	%	N	n	%	N	n	%
Nuisance alarms disrupt patient care.	205	186	91	26	25	96	39	38	98	4125	2928	71
Nuisance alarms reduce trust in alarms and cause staff to inappropriately silence alarms at times other than setup or procedural events.	203	168	83	26	26	100	39	38	98	4133	3223	78
Nuisance alarms occur frequently.	203	177	87	26	23	88	39	37	95	4124	3175	77
Unit layout interferes with alarm recognition and management.	201	148	74	NA	NA	NA	39	28	73	NA	NA	NA
When a number of devices (pumps) are used with a patient, it can be confusing to determine which device is alarming.	202	119	59	26	14	54	39	28	73	3916	1997	51
Alarm integration and communication systems would be useful for improving alarm recognition and management.	203	151	74	26	21	81	39	23	56	3786	2120	56
Unit noise interferes with alarm recognition.	203	135	67	26	12	47	39	21	54	3919	1646	42
Staff members are sensitive to alarms and respond quickly.	204	96	47	26	14	54	39	13	34	3935	2597	66
There have been frequent instances when alarms could not be heard and were missed.	204	141	69	26	9	35	39	12	32	3999	1159	29
Unit monitors with visual display of pump alarms (infusion, type of alarm, location) would be useful for improving alarm recognition and management.	202	171	85	NA	NA	NA	NA	NA	NA	NA	NA	NA

Abbreviations: AACN, American Association of Critical-Care Nurses; CCN, critical care nurse; HTF, Healthcare Technology Foundation; NA, not applicable; TCICU, transplant/cardiac intensive care unit.

[a]Percentages of AACN nurses who agreed or strongly agreed on pump-specific alarm survey statements compared with CCN 2017, TCICU 2015, and HTF 2011 nurses who agreed or strongly agreed on general clinical alarm survey statements.

[b]Petersen and Costanzo.[21]

[c]Sowan et al.[20]

[d]Korniewicz et al[16] and Healthcare Technology Foundation Clinical Alarms Committee.[17]

them with the findings of 3 other studies that measured clinical alarms in general. The intent was to assess whether CCNs perceive infusion pump alarms differently than clinical alarms.

Demographics

Based on the limited demographic data reported in the 3 comparison studies, it is unclear how similar or different the 4 study populations are. Cho et al[6] found no statistically significant ($P \leq .05$) difference in clinical alarm fatigue in ICU nurses when considering demographic characteristics. While demographic factors typically would be expected to have an impact on a study's results, these findings indicate that demographic factors may not play a large part in alarm perceptions.

Infusion Pump Alarm Perception Questions

The 10 pump alarm perception questions showed respectable reliability (Cronbach's $\alpha = 0.75$).[23] There was overwhelming agreement that infusion pump alarms disrupt patient care (91%) and occur frequently (87%). Considering that most infusion pump alarms interrupt infusion therapy and require direct action by the clinician, it is not surprising that nurses perceive pump alarms to disrupt patient care. This frequency perception is supported by a recent infusion pump alarm study that reported an average of 159 pump alarms every 24 hours on a 16-bed critical care unit.[3] Possible solutions to help augment the management of pump alarms might be the use of nursing unit central monitoring systems; intelligent alarm systems that automatically change settings and suppress alarms; alarm

TABLE 4

Comparison of Ranking of Issues That Affect Response to Alarms

Issues	AACN[a] (N = 205) (1 = most important, 5 = least important)		CCN 2017[b] (N = 26) (1 = most important, 5 = least important)		TCICU 2015[c] (N = 39) (1 = most important, 5 = least important)		HTF 2011[d] (N = 4276) (1 = most important, 5 = least important)	
	Mean	Ranking	Mean	Ranking	Mean	Ranking	Mean	Ranking
Difficulty identifying source of an alarm	2.69	2	3.65	3	2.94	1	4.61	2
Difficulty understanding the priority of an alarm	2.86	5	3.48	2	3.06	2	4.64	3
Difficulty hearing alarms when they occur	2.78	3	4.83	5	3.93	3	4.70	4
Frequent false alarms, leading to reduced attention or response	2.26	1	3.83	4	4.15	4	4.21	1
Inadequate staff to respond to alarms as they occur	2.83	4	3.13	1	4.23	5	4.87	6

Abbreviations: AACN, American Association of Critical-Care Nurses; CCN, critical care nurse; HTF, Healthcare Technology Foundation; TCICU, transplant/cardiac intensive care unit.

[a]AACN members' ranking of pump-specific questions compared with respondents' rankings in CCN 2017, TCICU 2015, and HTF 2011.

[b]Petersen and Costanzo.[21]

[c]Sowan et al.[20]

[d]Korniewicz et al[16] and Healthcare Technology Foundation Clinical Alarms Committee.[17]

delays; escalation; and distributed alarm systems, which forward critical infusion alarms to mobile devices.[9,24] It is encouraging that 85% of the nurses agreed that using unit monitors to visually display pump alarms could potentially be useful in improving alarm recognition and management. To date, however, there is no outcome research on the use of central monitoring specifically for infusion pump alarms, and forwarding of clinical alarms to cell phones has had mixed results.[24,25] Vockley[25] suggested that pushing pump alarms to cell phones exacerbated alarm fatigue, if alarms were not prioritized and selectively forwarded based on patient- and infusion-specific parameters.

Despite infusion pump companies' efforts to improve alarm recognition by having single-channel pumps, distinctive alarm tones, differentiating light signals, and real-time alarm status dashboards, 59% of the nurses agreed that when multiple pumps are being used on a patient, it can be confusing to determine which is alarming. In an emergent event when every second counts, confusion over which pump is alarming can be a matter of life and death for the critically ill patient. This may be an area that could benefit from hospital and infusion pump company partnerships to brainstorm, test, and implement creative solutions to improve pump alarm identification, escalation, and management.

Nurses' Perceptions of Infusion Pump Alarms and Clinical Alarms

The results of the current study showed differences between nurses' perceptions of infusion pump alarms and their perceptions of clinical alarms, in general, as described by Korniewicz et al,[16] Funk et al,[19] Sowan et al,[20] and Petersen and Costanzo.[21] The statement that elicited the most different results was "*there have been frequent instances where alarms could not be heard and were missed*." Thirty-five percent of the CCN 2017 nurses, 32% of the TCICU 2015 nurses, and 29% of the HTF 2011 nurses agreed with this statement when applied to clinical alarms; 69% of survey responses of AACN nurses agreed with the statement when applied specifically to infusion pump alarms. Looking at alarm volume produced by infusion pumps alone, Kurnat-Thoma and Shah[3] reported that the decibel sound level readings for 1 to 3 pumps at a room doorway ranged from 58 to 75 dB, while the overall noise in patient care areas was a mean of 56 dB with a peak of 76 dB in the progressive care unit. Thus, pump alarms may not be audible over general unit noise. However, Tegnestedt et al[4] found that monitor, ventilator, dialysis machine, and infusion pump alarms were all similar in volume, measuring between 82 and 85 dB. If these devices have no significant difference in actual alarm volumes in the clinical setting, then perhaps the nurses' perceptions of pump alarms not being heard and often missed are related to perceived criticality of these alarms. Specifically, physiological monitors and ventilators might be perceived as higher priority or more urgent than pump alarms (eg, a fatal arrhythmia or obstructed airway alarm vs an infusion complete alarm), and, therefore, nurses may be less critically "in tuned" to pump alarms and more likely to respond to them more slowly. Ultimately, the hospital environment has more device noise today than it

did when the WHO recommendations[2] were published. It will be necessary to reevaluate and determine optimal and realistic device alarm volumes and tones and the ability to differentiate different devices and levels of acuity. The AAMI Foundation is helping to address this through alarm design research based on auditory perception and cognition.[26] The researchers are identifying alarm acoustics that are easier to learn and localize, which will influence future national standards on medical device alarms.

Ranking Issues

With regard to the ranking of issues that affect response to infusion pump alarms, nurses clearly identified *frequent false alarms leading to reduced attention or response* as the most important issue. In infusion pumps, nuisance alarms can take the form of frequent air-in-line alarms as a result of microbubbles; occlusion alarms as a result of kinked administration sets or positional intravenous catheters; hold, expired, or inactivity alarms; and battery alarms. Evidence suggests that increased training and education can help reduce the number of nuisance alarms.[3,7,21,27] In a study involving a pediatric ICU, Manrique-Rodríguez et al[27] found that providing user training and support tools, as well as continuously monitoring results, decreased the number of unnecessary pump alarms and that alarms that sounded were taken more seriously. Kurnat-Thoma and Shah[3] characterized pump alarms and associated nurse perceptions across 6 care units, concluding that there was a need to improve staff education specific to clustering tasks around medical device alarms. Nurses have identified that lack of training contributes to the problem of alarm management, suggesting that increased training using real clinical scenarios with a focus on which alarms are nonactionable and how to set patient specific alarms may be useful.[7,21]

Study Limitations

This study has several limitations that should be considered. The sample was one of convenience and, for the most part, represented a self-selected group of CCNs. Approximately 80% of the survey respondents were attending a presentation on pump alarms. Of these, approximately 60% completed the survey before the presentation; 40% completed it following the presentation. Because the presentation included content on types and frequency of alarms, completing the survey after the presentation could have skewed respondents' perceptions and the survey results. While a randomized sample may produce similar results, the authors cannot assume that the present study results would apply to any other sample. Psychometric evidence to support the infusion pump-specific adapted HTF 2011 survey is limited, and ideally, the survey should undergo additional validity and reliability testing to improve confidence in the accuracy of the survey findings.

The use of the terms *nuisance* and *false* across all the surveys is another limitation, because the terms have not been defined and validated, and nurses taking the surveys may have different interpretations of them. For example, the Merriam-Webster dictionary[28] defines *nuisance* as "annoying or unpleasant," a *false alarm* as "an alarm sound that occurs when no valid triggering event has taken place," and the terms *nuisance*, *false*, *false positive*, *clinically insignificant*, and *nonactionable* are often used interchangeably without clear definition.[7,9,10] The first step to measure and understand perceptions around clinical alarms is to define and use consistent terminology. The AAMI Foundation is creating a standardized taxonomy regarding alarms, and some researchers are avoiding the use of *nuisance*, *false*, and *true alarms* because of their various interpretations.[7,8]

Furthermore, the classification of alarms may not apply to all equipment-related clinical alarms. For example, 1 classification is *actionable*, requiring intervention, as opposed to *nonactionable*, having no clinical relevance or requiring no clinical intervention.[9] Because most infusion pump alarms cause an interruption in the therapy and/or require clinical intervention, this type of classification may be less applicable to infusion pumps. A more meaningful way to classify pump alarms might be based on those that do not interrupt the infusion and those that do (eg, *delivery interruption alarms*). It also has been suggested that alarms be delineated based on level of priority (eg, high = urgent, medium = quick response, low = attention needed).[10] But how is an urgent versus a quick response operationalized? With infusion pumps, it's likely that the specific infusion and the patient's condition will determine the priority of addressing a delivery interruption alarm. For example, a bag-empty alarm for a stable patient on maintenance fluids would be a low priority, while a bag-empty alarm for a critically ill patient on epinephrine would require an urgent response. It will be important to define and classify critical pump alarms so that meaningful interventions and/or technologies can be implemented and evaluated. Possible technology solutions include (1) providing nurses with the ability to modify priority alarms, alarm delays, and escalations based on the patient and the infusion; and (2) providing real-time infusion alarm dashboards to prioritize alarm responses and avoid preventable alarms, such as bag-empty alarms.

Results of this study offer only a glimpse into nurse perceptions related to infusion pump alarms and by no means offer a complete picture. To date, no research has quantified alarm fatigue in nurses or connected alarm perceptions to actual measurement of nurse fatigue. Furthermore, there are only limited data on the frequency, duration, and other characteristics of infusion pump alarms,[3,29-31] and early research suggests that pump alarms may represent only a small portion of the clinical alarm issue, with ICU pumps being in an alarm state as little as 0.3% of total infusion time.[31] A benchmarking measurement standard for pump alarms should be established, and future work needs to collect data on infusion pump alarms across different pump types, models, and manufacturers. It is also hoped that further research, using robust sampling techniques

and instrumentation, will be able to add more detail to the infusion pump alarm story and offer insights into modifiable factors that potentially will be able to reduce the infusion pump alarm burden on nurses and patients without compromising patient safety.

CONCLUSION

Infusion pump alarms are problematic for CCNs, with the bulk of the problem stemming from a perceived high frequency of nuisance alarms that are believed to disrupt patient care. Compared with nurse perceptions of clinical alarms, perceptions of infusion pump alarms appear to be different. Based on these results, it may not be appropriate to apply data and recommendations about clinical alarms, in general, to infusion pump alarms. Future studies employing validated and reliable data collection tools and rigorous sampling techniques are needed to better understand nurse perceptions of infusion pump alarms and the impact of those perceptions on patient care. Once a better understanding of verifiable and repeatable infusion pump alarm issues is obtained, appropriate corrective solutions related to relevant and associated noise can be designed.

Health care industry collaboration is encouraged to establish pump alarm taxonomy, measurement standards, and benchmark data and to conduct necessary research to help identify creative solutions to improve pump alarm management. Potential solutions may include identifying non–decibel noise-producing alternatives to alert nurses to a patient's alarming pump; employing real-time dashboards, alarm prioritization, and patient-specific alarm customization technologies; and educating nurses on specific practices and pump configurations to help reduce unnecessary alarms. Recognizing the sampling and instrumentation shortfalls of the current study, it is recommended that further studies be conducted using more generalizable sampling techniques and psychometric evidence to support instrumentation.

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APPENDIX

Infusion Pump Alarm Survey

The purpose of this survey is to assess clinicians' perceptions about pump alarms. Please complete this survey by filling in the circle with your selection like this: ●

1. Gender	○ Female ○ Male	2. Age	__ __ yrs	3. Years in nursing	__ __ yrs	4. Hours worked	○ Full-time ○ Part-time
5. Type of unit	○ ICU ○ PICU ○ NICU ○ ER ○ OR ○ Tele ○ Med/Surg ○ Other: _____						
6. Job title	○ Staff Nurse ○ CNS/Educator ○ Manager ○ Other: _____						
7. Pump use	○ Every Workday ○ Occasionally *(few times a week)* ○ Rarely *(few times a month or less)*						

Based on your experience using pumps in your unit, please respond to the following statements.	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
1. Pump nuisance alarms occur frequently.	○	○	○	○	○
2. Pump nuisance alarms disrupt patient care.	○	○	○	○	○
3. Pump nuisance alarms reduce trust in alarms and cause staff to inappropriately silence alarms at times other than set up or procedural events.	○	○	○	○	○
4. There have been frequent instances when pump alarms could not be heard and were missed.	○	○	○	○	○
5. Staff are sensitive to pump alarms and respond quickly.	○	○	○	○	○
6. When a number of pumps are used on a patient, it can be confusing to determine which is alarming.	○	○	○	○	○
7. Unit noise (phones, pages, other device sounds) interferes with pump alarm recognition.	○	○	○	○	○
8. Unit size or layout interferes with pump alarm recognition and management.	○	○	○	○	○
9. Unit monitors with visual display of pump alarms (infusion, type of alarm, location) would be useful for improving alarm recognition and management.	○	○	○	○	○
10. Alarm integration with communication systems (pagers, cell phones, other) would be useful for improving alarm recognition and management.	○	○	○	○	○

Based on your experience, please rank the following issues concerning pump alarms in order from 1 (most important) to 5 (least important). **Use only one number per issue.	**MOST 1**	**2**	**3**	**4**	**LEAST 5**
1. Difficulty hearing pump alarms when they occur.	①	②	③	④	⑤
2. Difficulty identifying the source of a pump alarm.	①	②	③	④	⑤
3. Difficulty understanding the priority of a pump alarm.	①	②	③	④	⑤
4. Frequent false alarms, leading to reduced attention or response to pump alarms.	①	②	③	④	⑤
5. Inadequate staff to respond to pump alarms as they occur.	①	②	③	④	⑤

Abbreviations: CNS, clinical nurse specialist; ER, emergency room; ICU, intensive care unit; med/surg, medical/surgical; NICU, neonatal intensive care unit; OR, operating room; PICU, pediatric intensive care unit; Tele, telemetry.