


Alarm burden and the nursing care environment: a 213-hospital cross-sectional study

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ABSTRACT

Background High rates of medical device alarms in hospitals are a well-documented threat to patient safety. Little is known about organisational features that may be associated with nurses' experience of alarm burden.

Aims To evaluate the association between nurse-reported alarm burden, appraisals of patient safety, quality of care and hospital characteristics.

Methods Secondary analysis of cross-sectional survey data from 3986 hospital-based direct-care registered nurses in 213 acute care hospitals in New York and Illinois, USA. We evaluated associations of alarm burden with appraisals of patient safety and quality of care and hospital characteristics (work environment, staffing adequacy, size, teaching status) using χ^2 tests.

Results The majority of respondents reported feeling overwhelmed by alarms (83%), delaying their response to alarms because they were unable to step away from another patient/task (76%), and experiencing situations where a patient needed urgent attention but no one responded to an alarm (55%). Nurses on medical-surgical units reported these experiences at higher rates than nurses working in intensive care units ($p<0.001$). Alarm burden items were significantly associated with poorer nurse-reported patient safety, quality of care, staffing and work environment. Findings were most pronounced for situations where a patient needed urgent attention but no one responded to the alarm, which was frequently/occasionally experienced by 72% of those who rated their hospital's safety as poor versus 38% good, $p<0.001$; 80% who rated overall quality of care poor/fair versus 46% good/excellent, $p<0.001$ and 65% from poor work environments versus 42% from good work environments, $p<0.001$.

Conclusion Most nurses reported feeling overwhelmed by medical device alarms, and our findings suggest that alarm burden may be more pronounced in hospitals with unfavourable working conditions and suboptimal quality and safety. Because this was a cross-sectional study, further research is needed to explore causal relationships and the role of modifiable systems factors in reducing alarm burden.

INTRODUCTION

The hospital environment is replete with alarms from medical devices. Alarm management is a major component of nurses' workflows in many inpatient settings. However,

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Excessive and often non-actionable medical device alarms are a problem in acute care settings, contributing to patient safety events in which critical alarms are accidentally missed or ignored. Few studies focus on the system-level factors associated with nurses' experience of alarms.

WHAT THIS STUDY ADDS

⇒ Nurses who report poorer quality and safety, unfavourable work environments and staffing inadequacy at their hospital also report higher rates of alarm burden.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Modifiable organisational features, such as work environment and staffing ratios, may play a key role in improving alarm management and reducing nurses' experience of alarm burden.

high rates of alarms and their frequent lack of informativeness create unnecessary cognitive burden for clinicians.^{1–3} For example, one commonly used medical device—physiologic monitors—can produce hundreds of alarms per patient per day, the vast majority of which are invalid.^{2–7} Reports of patient safety events exist where important alarms have been missed, attributed to a 'cry wolf effect' and 'alarm fatigue'.^{8–13}

However, most investigations into the problem of alarms have been quality improvement or single-site research.^{2–3} Despite an appreciation that medical device alarms occur within complex systems,^{14–15} we lack large multisite studies that allow for comprehensive investigation of the relationship between nurses' experience of alarms and organisational factors across multiple institutions. In prior qualitative work, nurses have indicated that staffing and other elements of the work environment influence their management of alarms,¹⁶ but these relationships have largely not been quantitatively explored. We also suspect that when nurses are overburdened

by alarms, overall quality and safety of patient care may be diminished, in part because alarms increase nurses' workload.¹⁷

As an initial step towards addressing current gaps in knowledge, we leveraged the RN4CAST-NY/IL survey of registered nurses (RNs) working in 213 New York and Illinois hospitals¹⁸ to evaluate associations between nurses' reports of alarm burden (ie, feeling overwhelmed by alarms, delaying response to alarms, not responding to alarms, having work unnecessarily interrupted/delayed by alarms), appraisals of patient safety and quality of care, and hospital characteristics (eg, staffing, nurse work environment). We hypothesised that greater nurse-reported alarm burden would be associated with poorer overall appraisals of quality and safety of care. We also hypothesised that poorer staffing and work environments would be associated with greater nurse-reported alarm burden. The findings of this study inform new directions for research, advance our understanding of alarm-related patient safety and suggest the importance of modifiable organisational factors, including patient-to-nurse staffing ratios in the context of alarm-related patient safety and nurse alarm burden.

METHODS

Study design and setting

We conducted a secondary analysis of cross-sectional survey data. We leveraged a subset of items from a larger survey (RN4CAST-NY/IL) to address our research objectives. The original survey was distributed between April and June 2021 to all actively licensed RNs in New York and Illinois. Methods and main results from the survey have been described elsewhere.¹⁸ Nurses reported their demographic information (age, years of experience as an RN, highest level of education in nursing), evaluations of quality of care and patient safety in their hospital and characteristics of their hospitals (eg, staffing adequacy, nurse work environment). In the current study, we also leveraged a subset of survey items assessing nurses' experience of alarms from medical devices. Survey responses were anonymous, but nurses reported the name of their hospital, allowing for individual nurse responses to be aggregated to create hospital-level measures of staffing adequacy and work environments.

Sample

We included survey respondents in the current analysis if they were a direct-care staff RN working on an adult medical or surgical unit (ie, medical-surgical, oncology, step-down/intermediate care unit) or an intensive care unit (ICU) (ie, adult ICU, paediatric ICU, neonatal ICU). We excluded nurses who did not provide the name of their hospital or who did not respond to any of the survey questions about alarms. We further excluded nurses from hospitals where fewer than five nurses responded from that hospital, to ensure reliable estimates of the aggregated hospital-level measures. Over 16000 inpatient

nurses responded to the original survey; of those, 3986 RNs from 213 hospitals (127 in New York and 86 in Illinois) met our eligibility criteria and were included in our final analytic sample.

Variables

Alarm burden

'Alarm fatigue' is a commonly used but poorly defined term in healthcare literature.¹⁻³ Although publications have proposed various measures of alarm fatigue, none has been widely adopted,¹⁹⁻²¹ likely because the concept of alarm fatigue remains nebulous—described in various publications as cognitive or physical tiredness, desensitisation or even willful disregard for alarms.¹ For the current study, we, therefore, chose not to use the term alarm fatigue. Informed by review of existing alarm surveys²²⁻²⁵ and our team's expert knowledge in the field of alarm management, we constructed four items to evaluate nurses' perception of alarms as burdensome in their day-to-day practice ('alarm burden'). We adapted items from an internal hospital survey developed by co-authors (CB, HR) and a survey from the published literature.²⁵ The items are (1) 'I feel overwhelmed by the number of alarms I experience'; (2) 'I delay my response to alarms longer than I would like because I can't step away from another patient or task'; (3) 'I encounter situations where a patient needed urgent attention, but no one responded to the alarm'; (4) 'How frequently is your work interrupted or delayed by false, non-actionable or non-urgent alarms from medical devices?'. Five response options were offered for each question: frequently, occasionally, rarely, never or not applicable.

Although many alarm studies have focused specifically on physiologic monitors, we explicitly asked nurses to rate their perception of alarms from all sources (alarms from monitors, ventilators, pumps, call bells, etc) for three reasons: (1) we were interested in comprehensively assessing nurse alarm burden from all sources; (2) physiologic monitors are not used in all hospital units and (3) nurses may not accurately isolate their experience of alarm burden from one device type. Nurses were also asked if they use continuous monitoring (cardiac, respiratory, pulse oximetry) on their unit and the frequency of continuous monitoring (ie, for all patients, for some patients or never).

Nurse demographics

Nurse demographics included highest degree in nursing, which we dichotomised as bachelor's of science in nursing (BSN) or higher (includes bachelors, masters, doctoral degree) and non-BSN (includes associates and diploma) and years of experience as a RN.

Patient safety and quality of care

Nurses rated the overall safety of nursing care in their hospital on a 4-point scale using grades of 'A' (excellent) through 'F' (failing). Nurses indicated quality of nursing care in their hospital on a 4-point scale ranging from

'excellent' to 'poor'. For analysis, we dichotomised safety grades into 'good' (A/B) or 'poor' (C, D and F) and quality of care into 'excellent/good' and 'poor/fair'. Both scales have been used as reported in prior research.^{26 27} We also considered nurses' reports of missed nursing care to be an indicator of quality/safety. Using an established method of assessing missed care,^{28 29} nurses were asked to reflect on their most recent shift worked and report which (if any) of 9 nursing care activities were necessary but left undone due to lack of time: (1) comfort/talk with patients, (2) educating patients and family, (3) develop/update patient plan of care, (4) adequate patient surveillance, (5) Adequately document nursing care, (6) administer medications on time, (7) skin care, (8) coordinate patient care, (9) pain management. We created a composite measure of total number of care activities missed by a nurse.

Hospital characteristics

Nurse work environment

Nurses rated their work environment using an abbreviated version of the Practice Environment Scale of the Nursing Work Index (PES-NWI).^{30 31} The PES-NWI is a validated instrument endorsed by the National Quality Forum that measures the organisational characteristics of the nurse work environment. Nurse survey participants were asked to respond to how strongly they agreed or disagreed that the following features were present in their job: administration that listens and responds to nurse concerns, a clear philosophy of nursing that pervades the patient care environment, a supervisor who is a good manager and leader, good team work between nurses and physicians. Nurses rated their agreement on a four-point Likert scale from 'strongly agree' to 'strongly disagree'. We aggregated nurse responses to the hospital-level by averaging the scores and then categorising the hospital as a 'poor', 'mixed' or 'good' work environment.

Staffing adequacy

We used a measure of staffing adequacy that has been validated in prior work.³² RNs reported how strongly they agreed or disagreed with the statement: 'there is enough staff to get the work done'. For analysis, we dichotomised RN responses as 'somewhat disagree/strongly disagree' and 'somewhat agree/strongly agree'. We aggregated the dichotomised responses to create a hospital-level measure of the proportion of RNs who somewhat or strongly disagreed 'there is enough staff to get the work done'. Then, we trichotomised the hospital-level proportions (ie, 0%–33%, 34%–66%, 67%–100%), with the highest category representing hospitals with the poorest staffing adequacy.

Hospital teaching status and size

We matched hospitals to American Hospital Association (AHA) Annual Survey data to obtain hospital teaching status and size. Teaching status was defined by the number of residents per hospital bed: non-teaching hospitals had

no residents, minor teaching hospitals had one or fewer residents to every four hospital beds, and major teaching hospitals had more than one resident to every four hospital beds. We categorised hospital size by number of beds: low (≤ 100 beds), medium (101–250 beds) and high (> 250 beds).

Statistical analysis

We report descriptive statistics as percentages, counts, means and SD. We dichotomised responses to alarm burden items into frequently/occasionally and rarely/never. We used χ^2 to test for significant differences in responses to alarm burden items by practice setting, nurse demographics, safety, quality of care and hospital characteristics. For significant results of the global χ^2 test for > 2 groups, we conducted post hoc tests to determine which group comparisons were driving the significant results and used Simes correction for multiple comparison. We examined the association between alarm burden questions and mean number of missed nursing care activities using t tests. We used individual nurse-level responses for analyses of practice setting, nurse demographics, patient safety, quality of care and missed nursing care. We used nurse responses aggregated by hospital for analyses of hospital characteristics (work environment, staffing adequacy, teaching status and size). We used Stata V.17 for statistical analysis. Our Institutional Review Board determined the study exempt (category 4).

RESULTS

Table 1 displays the characteristics of our sample (n=3986 nurses). Most worked in medical-surgical units (61.2%, n=2439) and had at least a BSN degree (80.7%, n=3215). More than 60% of the sample had ≤ 10 years of experience. Table 2 displays the associations between nurse characteristics and alarm burden. The majority of nurses frequently or occasionally felt overwhelmed by the

Table 1 Characteristics of hospital-based nurse respondents (N=3986)

	N	%
Practice setting		
Medical and surgical	2439	61.2
Intensive care unit	1547	38.8
RN education		
BSN or higher	3215	80.7
Non-BSN	771	19.3
RN years of experience		
0–5 years	1637	41.1
6–10 years	779	19.5
11–15 years	437	11.0
>15 years	1132	28.4
BSN, bachelor's of science in nursing; RN, registered nurse.		

Table 2 Nurse-reported alarm burden by practice setting characteristics and nurse demographics

	% and N of nurses who frequently or occasionally...											
	Felt overwhelmed by the number of alarms			Delayed response to alarms because can't step away from another patient/task			Encountered situations where a patient needed urgent attention, but no one responded to alarms			Had work interrupted or delayed by false, nonactionable or non-urgent alarms		
	%*	N†	p‡	%*	N†	p‡	%*	N†	p‡	%*	N†	p‡
All nurses (n=3986)	82.9	3262	–	75.6	2970	–	55.4	2164	–	46.0	1793	–
RN education												
BSN or higher (n=3215)	82.8	2627	0.915	74.9	2371	0.039	54.1	1703	0.001	45.0	1413	0.006
Non-BSN (n=771)	83.0	635		78.5	599		60.7	461		50.5	380	
RN years of experience												
0–5 years (n=1637)	86.3	1400	<0.001	78.4	1272	<0.001	56.3	906	0.024	39.6	632	<0.001
6–10 years (n=779)	85.6	661		77.8	598		58.8	451		44.0	334	
11–15 years (n=437)	80.8	345		74.7	318		54.5	232		44.8	192	
>15 years (n=1132)	76.8	855		70.4	781		52.0	574		57.3	635	
Practice setting												
Intensive care unit nurses (n=1547)	80.2	1233	<0.001	68.8	1056	<0.001	44.9	685	<0.001	49.4	746	0.001
Medical and surgical nurses (n=2439)	84.6	2029		80.0	1914		62.1	1479		43.9	1047	
Continuous patient monitoring												
Always/sometimes used on nurse's unit (n=3821)	83.6	3174	<0.001	76.0	2879	0.019	55.5	2092	0.421	46.4	1736	0.049
Never used on nurse's unit (n=151)	63.3	81		66.9	85		51.9	67		38.0	54	

*Denominators used to calculate percentages differed from totals in column 1 due to exclusion of missing.
†May not sum to total due to missing.
‡P-value for χ^2 test.
BSN, bachelor's of science in nursing.

number of alarms they experienced (82.9%, n=3262), delayed response to alarms because they were unable to step away from another patient or task (75.6%, n=2970) and frequently or occasionally were in situations where a patient needed urgent attention, but no one responded to the alarm (55.4%, n=2164). Forty-six per cent of nurses (n=1793) report having work frequently or occasionally interrupted or delayed by false, non-actionable or non-urgent alarms.

Nurses with and without a BSN degree were similarly overwhelmed by alarms (82.8% vs 83.0%, p=0.915), but those without a BSN were more likely to report encountering situations where a patient needed urgent attention but no one responded (60.7% vs 54.1%, p<0.001) and having work interrupted/delayed by false, non-actionable or non-urgent alarms (50.5% vs 45.0%, p=0.006). Nurses with more years of experience were less likely to feel overwhelmed, delay responses to alarms and encounter situations where no one responded to an alarm, as compared with nurses with fewer years of experiences. The differences appeared primarily between nurses with ≤ 10 years

of experience and those with more than 10 years; in post hoc analyses, we found no significant difference on these items between nurses with 0–5 years and 6–10 years of experience, or between nurses with 6–10 years and 11–15 years of experience. However, nurses with the most years of experience were more likely to report work interruptions from alarms as compared with less experienced nurses.

Nurses on medical-surgical units experience alarm overwhelm, delay responses to alarms and encounter situations where no one responds to patient alarms at significantly higher rates than nurses working in ICUs. However, ICU nurses were significantly more likely to report having work interrupted by alarms (49.4% vs 43.9%, p<0.001). Most nurses reported working in settings where continuous monitoring of heart rate, respiratory rate or pulse oximetry is always or sometimes used (95.9%, n=3821). These nurses reported alarm overwhelm at considerably higher rates than nurses who never had patients on continuous monitoring. However, more than half of the nurses with no continuous monitoring used on their

unit still reported frequently or occasionally feeling overwhelmed by alarms.

The relationship between nurse-reported alarm burden and measures of patient safety and quality of care is in [table 3](#). Half of nurses (n=2000, 50.2%) gave their hospital a poor patient safety grade and 26.9% of nurses gave the overall quality of nursing care in their hospital a poor/fair grade (n=1073). Poor patient safety grade and poor/fair quality of care ratings were both significantly associated with higher rates of nurses who felt overwhelmed by alarms, delayed responses to alarms, encountered situations where no one responds to patient alarms and had work interrupted by alarms. Notably, the proportion of nurses who gave their hospital a poor safety grade and reported frequently or occasionally encountering situations where no one responds to an alarm was nearly double that of nurses who gave their hospital a good safety grade (72.0% vs 38.4%, p<0.001). A similar finding was noted for overall quality of nursing care.

In addition, we examined the relationship between alarm overwhelm and missed nursing care activities. Nurses who frequently or occasionally felt overwhelmed by alarms reported more missed care activities on average than those who rarely or never felt overwhelmed by alarms (mean 3.9 (SD 2.5) vs mean 2.5 (SD 2.1), p<0.001)

[Table 4](#) displays the characteristics of hospitals (n=213), where nurse respondents worked. The sample was varied in terms of nurse-rated hospital work environments and staffing adequacy. The largest proportion of hospitals were non-teaching (46.5%, n=99), as compared to minor (31%) or major teaching (22.5%), and were >250 beds (58.7%, n=125).

[Table 5](#) presents nurse reports of alarm burden by hospital characteristics. In general, nurses working in hospitals characterised as having good nurse work environments reported alarm burden at significantly lower rates than nurses in mixed or poor work environments. However, in post hoc analysis, nurses in poor work environments were not significantly more likely to report feeling overwhelmed by alarms than those in good work environments (80.9% vs 79.8%, p=0.621). Differences were most pronounced for the item ‘I encounter situations where a patient needed urgent attention but no one responded’, with 42.1% of nurses in good work environments reporting that they frequently or occasionally encounter these situations compared with 65.4% of nurses working in poor environments (p<0.001). Similarly, nurses working in hospitals with the best staffing frequently or occasionally encountered these situations 45.0% of the time, compared with 65.6% of the time for nurses from hospitals with the worst staffing (p<0.001).

The relationships between other hospital characteristics and nurse alarm burden were somewhat mixed. Nurses in major teaching hospitals were less likely to report frequently or occasionally experiencing any of the items. Nurses in medium-sized hospitals were more likely to encounter situations where no one responded to patient needs (60.2%) compared with nurses in small

Table 3 Nurse-reported alarm burden by patient safety and quality of care

	% and N of nurses who frequently or occasionally...												
	Feel overwhelmed by the number of alarms N=3262		Delay response to alarms because can't step away from another patient/task N=2970		Encounter situations where a patient needs urgent attention, but no one responds to alarm N=2164		Have work interrupted or delayed by false, non-actionable or non-urgent alarms N=1793						
	%	N	%*	N	P†	%*	N	P†	%*	N	P†		
Total													
Patient safety grade‡													
Good (A/B)	49.8	1986	77.7	1520	<0.001	65.9	1282	<0.001	38.4	742	<0.001	38.0	733
Poor (C/D/F)	50.2	2000	87.9	1742		85.2	1688		72.0	1422		53.9	1060
Overall quality of nursing care‡													
Excellent/good	73.1	2913	80.7	2318	<0.001	72.0	2061	<0.001	46.3	1320	<0.001	41.7	1186
Poor/fair	26.9	1073	88.8	944		85.4	909		79.9	844		57.6	607

*Denominators used to calculate percentages differed from ‘Total’ column due to exclusion of missing.

†P-value for χ^2 test.

‡Nurse-reported patient safety grade and quality of nursing care for their hospital.

Table 4 Characteristics of hospitals in which nurse respondents work (N=213)

	N*	%
Hospital work environment		
Good	51	23.9
Mixed	107	50.2
Poor	55	25.8
Proportion of nurses reporting not enough staff to get work done		
0%–33%	81	38.0
34%–66%	67	31.5
67%–100%	65	30.5
Teaching status		
Nonteaching	99	46.5
Minor	66	31.0
Major	48	22.5
Size		
Small (≤ 100 beds)	7	3.3
Medium (101–250 beds)	76	35.7
Large (>250 beds)	125	58.7
Hospitals had to have at least five nurse respondents to be included in analysis.		
*May not sum to total due to missing.		

hospitals (44.2%) ($p=0.024$) and large hospitals (54.7%) ($p=0.008$).

DISCUSSION

The majority of hospital nurses report experiencing alarm burden frequently or occasionally, especially feeling overwhelmed by alarms and delaying responses to alarms because they are unable to step away from another patient or task. Perceptions of high alarm burden were more frequent among nurses working on medical-surgical units as compared with ICUs and among nurses working in hospitals characterised by poor nurse work environments and staffing inadequacy. Nurses who reported overall poor safety and quality of care in their hospital also had higher rates of alarm burden. Our findings confirmed our hypotheses, that there is an association between nurses' alarm burden and appraisals of quality and safety of care, and that there is an association between modifiable organisational factors—work environment and staffing—and alarm burden.

We are aware of only one other large-scale survey that explored the extent of the problem of medical device alarms across nurses from multiple institutions. The survey was distributed through professional organisations in the USA by the Healthcare Technology Foundation (HTF) three times over a 10-year period.^{22–24} Nurses made up the majority of respondents, and their responses indicated that alarms were widely problematic and remained so over the 10-year period. The last HTF

survey was conducted in 2016; our findings demonstrate that 5 years later, medical device alarms remain problematic for nurses. The HTF survey did not examine variation in nurse alarm burden across hospital organisational factors and characteristics, as our study does.

The results of our study demonstrate that nurse-reported alarm burden may be most pronounced outside the ICU. To date, alarm research has predominantly focused on the ICU, which relies heavily on the use of continuous physiologic monitoring.²⁵ However, as monitoring technologies become less expensive and more compact, continuous monitoring is increasingly being adopted in non-ICU hospital settings, often with little regards for the impact of alarm burden on nursing.^{33–37} Nurses outside the ICU typically care for more patients at a time, which may contribute to their reports of high alarm burden. Although small in number, we also found that the majority of nurses working on units where continuous physiologic monitoring was never used still had high rates of feeling overwhelmed by alarms. Almost all alarm research focus on physiologic monitors, but clearly alarms from other sources (eg, call bells, bed alarms and IV pumps) are problematic for nurses.³⁸ Alarm management strategies need to consider the entire ecosystem of alarms for which nurses are responsible, both in and outside the ICU.

Our study also demonstrates that nurse-reported alarm burden is associated with appraisals of overall quality and safety of care. Case reports of adverse patient outcomes related to missed alarms exist^{8–10,39} but are rare. Our study adds quantitative evidence that alarm burden and overall quality and safety are related, although future research using independent measures of hospital quality and safety (vs nurses' appraisals) are warranted. Findings were especially pronounced for nurses' report of encountering situations where a patient needed urgent attention, but no one responded to the alarm, which was frequently/occasionally experienced at almost double the rate by nurses who gave their hospitals poor patient safety and quality grades. Although a cause and effect relationship between alarm burden and work environment characteristics cannot be established by the cross-sectional nature of our study, the association indicates that alarm burden may be either an important contributor to or symptom of poor quality care. Alarms that are overly burdensome may impact nurses' ability to care for their patients, or units with overall poor safety and quality might also suffer from poor alarm management.

Finally, we found that both staffing and work environment were associated with alarm burden. Although monitoring devices are often thought to augment or extend nurses' ability to care for patients, managing and responding to alarms from medical devices also increase nurses' workloads.¹⁷ Additionally, poor work environments may be characterised by worse interprofessional working relationships,³¹ which may translate into more unnecessary alarms. For example, if nurses are not given autonomy to adjust alarm settings without an order and

Table 5 Nurse-reported alarm burden by hospital characteristics

	% and N of nurses who frequently or occasionally...											
	Feel overwhelmed by the number of alarms N=3262			Delay response to alarms because can't step away from another patient/task N=2970			Encounter situations where a patient needs urgent attention, but no one responds to alarm N=2164			Have work interrupted or delayed by false, non-actionable or non-urgent alarms N=1793		
	%	N*	P†	%	N*	P†	%	N*	P†	%	N*	P†
Work environment												
Good	79.8	575	0.001	71.5	514	0.001	42.1	299	<0.001	39.6	281	<0.001
Mixed	84.7	1922		75.4	1705		55.4	1250		45.4	1019	
Poor	80.9	765		79.2	751		65.4	615		52.3	493	
Proportion of nurses reporting not enough staff to get work done												
0%–33%	80.8	1146	0.008	70.3	995	<0.001	45.0	631	<0.001	42.7	596	0.001
34%–66%	82.9	1191		77.1	1105		57.9	828		46.3	660	
67%–100%	85.6	925		80.6	870		65.6	705		50.0	537	
Teaching status												
Nonteaching	84.0	1176	0.024	77.7	1086	<0.001	56.4	784	<0.001	46.8	650	0.017
Minor	84.4	860		77.9	794		61.1	620		49.0	494	
Major	80.8	1226		72.1	1090		50.6	760		43.4	649	
Size												
Small (≤100 beds)	69.2	36	0.025	73.1	38	0.057	44.2	23	0.008	53.9	28	0.096
Medium (101–250 beds)	83.9	594		79.2	559		60.2	425		49.2	344	
Large (>250 beds)	83.0	2606		75.0	2349		54.7	1704		45.4	1409	
*May not sum to total due to missing. †P-value for χ^2 test.												

relationships with physicians are poor, alarm settings may be less likely to be customised appropriately for the patient, resulting in more unnecessary alarms.

Implications for practice and research

Modifiable organisational aspects of the hospital work environment, such as staffing ratios, may be key to reducing nurse alarm burden. Most studies use alarm rates (eg, alarms per patient per day) as the outcome of interest^{2,4–6}; however, there is little evidence linking alarm rates to other meaningful outcomes. In one study, Sowan *et al*⁴⁰ did not find that reducing alarms changed nurses' experience of alarms, which suggests that reducing the number or frequency of patient alarms is an insufficient solution, potentially because contextual factors such as staffing and work environment matter for how alarms are perceived and managed.⁴¹ Our study adds perspective for reducing nurse alarm burden by considering the role of system-level approaches, such as fostering work environments where nurses have enough time to care for patients and have clinical autonomy and support from management. Our findings are not surprising given that both

staffing and work environment are repeatedly linked to a variety of nurse and patient outcomes.^{30 32 42 43}

We also introduced a method for assessing nurses' perceptions of alarm burden using four survey items, which may be a useful expansion on or replacement for the nebulous concept of 'alarm fatigue' in future research. We found that the nurse-reported alarm burden survey items were associated with widely used methods for measuring nurse-reported quality and safety patient care in the hospital. Future efforts to validate a composite score from the survey items could result in a concise, scalable outcome measure for interventional research and quality improvement projects.

Strengths and limitations

The results of the study should be interpreted within the context of the study design. The cross-sectional design precludes our ability to establish causality of the associations. Nevertheless, we provide evidence of bivariate associations to guide future research on the antecedents (predictors) and consequences (outcomes) of alarm burden and to inform organisational interventions to

reduce alarm burden. Our study also relies on nurse-reported measures of quality and safety, and although an important indicator of quality and safety in hospitals, other measures of quality and safety exist. Future research exploring the association between independent measures of quality and safety and alarm burden would provide additional perspective. We also did not assess use of monitor ‘watchers’ (technicians) at these hospitals. The presence of monitor watchers may affect nurses’ perception of alarm burden. Although monitor watcher practice differs across institutions, they typically are responsible for alerting nurses to potentially concerning changes in patient condition and may offload some of the responsibility of alarm management.^{44 45} Finally, our study includes hospital nurses from New York and Illinois, which reduces generalisability to US hospitals nationally and in other countries; however, we believe that this study represents the largest study of alarm burden in terms of hospitals represented (N=213) and hospital-based direct-care nurses (N=3986).

CONCLUSIONS

Nurses’ timely response to medical device alarms and call bells is critical for optimal patient outcomes, such as detection and prevention of patient deterioration. We found that nurses’ reports of high alarm burden (ie, feeling overwhelmed by alarms, delaying response to alarms, not responding to alarms, having work unnecessarily interrupted/delayed by alarms) were aligned with their reports of overall poor care quality and patient safety in their hospital as well as poor staffing and unfavourable work environments. The results of our study indicate that the problem of alarms cannot be solved in isolation and must be addressed concurrently with foundational issues such as improving nurse staffing and work environments.

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Patient consent for publication Not applicable.

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