Received: 7 November 2020 | Revised: 4 March 2021 | Accepted: 12 March 2021

DOI: 10.1111/aas.13824

CLINICAL INVESTIGATION

acta Anaesthesiologica Scandinavica

Clinical alarms and alarm fatigue in a University Hospital Emergency Department—A retrospective data analysis

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Funding information
This work was supported by Finnish Governmental Research Grant.

Abstract

Background: Alarm fatigue is hypothesized to be caused by vast amount of patient monitor alarms. Objectives were to study the frequency and types of patient monitor alarms, to evaluate alarm fatigue, and to find unit specific alarm threshold values in a university hospital emergency department.

Methods: We retrospectively gathered alarm data from 9 September to 6 October 2019, in Jorvi Hospital Emergency department, Finland. The department treats surgical, internal and general medicine patients aged 16 and older. The number of patients is on average 4600 to 5000 per month. Eight out of 46 monitors were used for data gathering and the monitored modalities included electrocardiography, respiratory rate, blood pressure, and pulse oximetry.

Results: Total number of alarms in the study monitors was 28 176. Number of acknowledged alarms (ie acknowledgement indicator pressed in the monitor) was 695 (2.5%). The most common alarm types were: Respiratory rate high, 9077 (32.2%), pulse oximetry low, 4572 (16.2%) and pulse oximetry probe off, 4036 (14.3%). Number of alarms with duration under 10 s was 14 936 (53%). Number of individual alarm sounds was 105 000, 469 per monitor per day. Of respiratory rate high alarms, 2846 (31.4%) had initial value below 30 breaths min^{-1}. Of pulse oximetry low alarms, 2421 (53.0%) had initial value above 88%.

Conclusions: Alarm sound load, from individual alarm sounds, was nearly continuous in an emergency department observation room equipped with nine monitors. Intervention by the staff to the alarms was infrequent. More than half of the alarms were momentary.

Editorial Comment

This report describes alarm load in large university hospital emergency department, and risk for alarm fatigue. From a sample of active monitors, many thousand alarms were recorded during one month, equivalent to 125 alarms per day per monitor. Of these only very few were acknowledged, possibly due to alarm fatigue. The authors demonstrate that adding a further 10-s delay to the alarm activation thresholds would eliminate many of these alerts. The findings highlight the need to identify and implement relevant alert thresholds for clinical complications.

1 | INTRODUCTION

Alarm fatigue makes medical staff desensitized to clinical alarms from patient monitoring devices.[1] This leads to slower response or total ignorance of alarms. Many studies on alarm fatigue focus on the intensive care (ICU) environment.[2] More recently, other areas such as paediatrics and emergency medicine have also gained more attention. The reasons behind alarm fatigue are thought to be excessive alarm exposure (up to 10 000 per room per day) and poor positive predictive value of alarms (as low as 1%).[2] Studies have also shown that a small number of patients usually generate most of the alarms in the units.[3] Methods of reducing alarm fatigue have mainly focused on reducing the number of alarms, by for example changing monitor alarm thresholds, adding time delays, changing the electrodes daily, and by providing education to the staff.[4,5]

Alarm fatigue is associated with patient harm and even death. In 2013, the Joint Commission reported 98 alarm-related events, of which 80 resulted in death. Alarm fatigue was the most common contributing factor among these events.[6] The Joint Commission has announced alarm safety as a national patient safety goal for several years now,[1] and multiple other organizations have also raised alarm safety as a top priority.[7]

There are only few studies on alarm fatigue in the context of emergency medicine. They show high amounts of alarms (up to 7.4 per hour per patient),[8] low rates of change in clinical management in response to alarms (as low as 0.2%),[9] and moderate correspondence of patient clinical status and alarms (75%).[10] The most common alarm type found was premature ventricular contraction.[11]

Setting monitor values according to an evaluated unit's average alarm data is encouraged.[1,12] However, available knowledge of clinical alarms, alarm fatigue, and suggested alarm thresholds in emergency departments is limited. We examined alarm fatigue and clinical alarms in a Finnish university hospital emergency department. The key objective of this study was to evaluate the types and frequencies of patient monitoring device clinical alarms in an emergency department. The secondary objectives were to identify the unit-specific alarm thresholds and to evaluate alarm fatigue.

2 | METHODS

2.1 | Study unit and patients

Ethical approval for this study (Ethical Committee No HUS/486/2018) was provided by the Ethical Committee II of Helsinki University Hospital, Helsinki, Finland on 6 June 2018. The study was performed in Jorvi Hospital Emergency department during autumn 2019 by collecting patient monitoring device clinical alarms. The department treats internal medicine, surgical, and general medicine patients aged 16 and older. The average number of patients in a month is 4600–5000.

2.2 | Patient monitors

Patient monitor alarms of the study department were collected remotely by the monitor manufacturer (General Electric) over 4 consecutive weeks (9 September to 6 October 2019). The department consisted of four observation rooms with nine monitors each and one intensive monitoring room with five monitors. There were also additional monitors; the total number of patient monitors was 46. Patients that required observation-level treatment were randomly allocated to a free bed in one of the four observation rooms. Eight randomly selected monitors from the observation rooms were included in the study. Nurses are permitted to change the patient monitor alarm thresholds, within a predetermined range, according to their prevailing clinical evaluation.

Monitors in the department were of type CARESCAPE B850. The monitored modalities included electrocardiography (ECG), respiratory rate (RR) from an impedance sensor, invasive and non-invasive blood pressure, and pulse oximetry (SpO_2). Alarms produced by the monitors are categorized by built-in algorithms into three priority levels: high, medium, and low according to the alarm type, and in some cases by the duration of the alarm condition. Once the alarm is triggered, a high-priority alarm sounds every 7 s, a medium-priority alarm every 20 s, and a low-priority alarm once. Alarms sound and stay active until they are silenced or acknowledged (ie alarm acknowledgement indicator pressed in the monitor), or if the sensed parameter spontaneously returns to a value outside the alarm threshold. If multiple alarms co-occur, the one with the highest priority remains active until the situation changes.

An alarm is produced after an averaged parameter value is sensed to cross a pre-set threshold and a possible time delay has passed. In providing parameter values, the monitors had the following averaging settings: Heart rate (HR) used a median of last 12 s; RR from the impedance sensor used averaging of four breaths; and SpO_2 lead used an average of last 12 s. The default alarm threshold settings were: RR high, 25 breaths min^{-1}; SpO_2, 90%; Bradycardia/HR low 40 bpm; and Tachycardia/HR high 150 bpm. Alarm delays in the monitors were as follows: Bradycardia, Tachycardia, and HR low/high were given without time delay; SpO_2 and RR alarms used a delay of 5 s. It should be noted that in the following results "Bradycardia" vs "HR Low" and "Tachycardia" vs "HR High" may use different sensors for measurement of HR, defined by built-in algorithms.

2.3 | Data analysis

From the collected monitor data, we descriptively analysed the number, types, values and durations of alarms. We chose 10 seconds as a cut-off point for alarm durations as it is reasonable to assume that a nurse will not have enough time to notice the alarm, go to the patient, and to begin and complete the necessary actions; these alarms had spontaneously disengaged. The primary outcomes were the number, types, values and durations of alarms. The secondary outcome was the estimated number of alarms after a hypothetical change in alarm thresholds and an additional time delay. For the confidence interval, and to estimate the overall number of all observation room alarms, we assumed that all the remaining observation room monitors not included in the study produced alarms as much as the monitor in our study that produced most alarms.

3 | RESULTS

3.1 | Alarm Frequencies

During the 4-week study period there were 28 176 (11.58%, 95% confidence interval [CI] 11.45 to 11.71, see Methods) alarms produced by the study monitors, 125.8 alarms per monitor per day. Of these, 301 (1.1%) alarms had been pre-silenced, 695 (2.5%) alarms were acknowledged, and alarm audio was paused 467 (1.7%) times so that pausing usually followed acknowledgement. Alarm threshold was other than pre-set value in 604 (2.1%) alarms and of these, 492 (81.5%) were SpO_2 low alarms. Number of alarms related to the physiological status of a patient was 22 193 (78.8%) and to the technical status of the monitoring device, 5983 (21.2%).

3.2 | Alarm types

The most common alarm types were RR high (9077, 32.2%), SpO_2 low (4572, 16.2%), and SpO_2 probe off (4036, 14.3%). The average duration of these alarms was 25 seconds (±1 min 12 s), 18 seconds (±40 s) and 3 minutes 54 seconds (±19 min 3 s), respectively. The number of alarms with duration under 10 seconds (momentary alarm) among the mentioned alarms was 3939 (43.4%), 2264 (49.5%), and 1529 (37.9%), respectively (Table 1).

Regarding the source of alarm data, that is, the sensors used, most common alarms were: Impedance sensor for RR 10 380 (36.8%), ECG related 8779 (31.2%), SpO_2 sensor 8640 (30.7%), and the number of momentary alarms was 4458 (42.9%), 6586 (75.0%), and 3814 (44.1%), respectively. We also observed that “HR Low” and “Bradycardia” usually appeared simultaneously as did “HR High” and “Tachycardia”.

The number of alarms per monitor was from 1583 to 7685. Seven out of eight monitors had the same three most common alarm types in varying order. The monitor with the greatest number of alarms also had a differing most common alarm type; this was ventricular tachycardia (VT) 2679 (34.9% of monitor total and 98.1% of the total number of all VT alarms), and this occurred during one particular day within a few hours.

3.3 | Alarm durations and values

The number of alarms with duration under 10 seconds was 14 936 (53.0%) (Table 1). On the other hand, there were 12 alarm types that produced alarms with an average duration of 5 minutes or more (up to an average of 19 min 28 s, longest individual durations >5 h), 2097 (7.4%) alarms together. The most common alarm among those of longer duration, was medium-priority SpO_2 probe off alarm (1313).

The priority level of the alarms varied. Most alarms were of low priority (12 749, 45.2%). The most common alarm types for each priority level are shown in Table 2.

Of RR high alarms, 2846 (31.4%) had value below 30 breaths min^{-1}. Of SpO_2 low alarms, 2421 (53.0%) had value above 88%. Alarm values by alarm type for the most common alarm types are shown in Table 3.

TABLE 1 Top 10 out of 43 most common alarm types

Alarm type	Alarm threshold value	Number of alarms	Percentage of alarms	Average duration (min:s ± SD)	Number of momentary alarms	Percentage of momentary alarms
Respiratory Rate High, (breaths min^{-1}) (P)	25	9077	32.2%	00:25 ± 01:12	3939	43.4%
Pulse oximetry low, (%) (P)	90	4572	16.2%	00:18 ± 00:40	2264	49.5%
Pulse oximetry probe off (T)	N/A	4036	14.3%	03:54 ± 19:03	1529	37.9%
Ventricular tachycardia (P)	[a]	2730	9.7%	00:03 ± 00:06	2518	92.2%
ECG leads off (T)	N/A	1183	4.2%	00:54 ± 02:27	675	57.1%
Bradycardia, bpm (P)	40	1075	3.8%	00:10 ± 00:32	895	83.3%
Apnoea (P)	[b]	1038	3.7%	00:16 ± 00:21	379	36.5%
Heart rate low, bpm (P)	40	945	3.4%	00:12 ± 00:37	744	78.7%
Tachycardia, bpm (P)	150	647	2.3%	00:10 ± 00:50	542	83.8%
Heart rate high, bpm (P)	150	616	2.2%	00:10 ± 00:53	515	83.6%
Total (TOP 10)		25 919	92.0%	00:53 ± 07:41	14 000	54.0%
Total (all alarms)		28 176	100%	01:15 ± 09:17	14 936	53.0%

Note: (P), physiological alarm; (T), technical alarm; N/A, not applicable.

[a]Persistent ventricular rhythm over 100 bpm.

[b]No breaths within the preceding 20 s.

TABLE 2 Top five most common alarm types categorized by priority level

Alarm type by priority	Number of alarms	Average duration (min:s ± SD)	Number of momentary alarms	Percentage of momentary alarms
High priority	4410	00:27 ± 01:38	3225	73.1%
Ventricular tachycardia	2730	00:03 ± 00:06	2518	92.2%
Pulse oximetry low	592	00:55 ± 01:42	167	28.2%
ECG leads off	304	02:32 ± 04:24	117	38.5%
VT >2	282	00:11 ± 00:28	240	85.1%
Apnoea	110	00:36 ± 00:58	32	29.1%
Medium priority	11 017	02:11 ± 13:17	5713	51.9%
Pulse oximetry low	3878	00:13 ± 00:11	2030	52.3%
Pulse oximetry probe off	1313	11:29 ± 32:06	341	26.0%
Respiratory rate high	1183	01:24 ± 03:06	252	21.3%
Bradycardia	1006	00:06 ± 00:13	863	85.8%
Heart rate low	887	00:08 ± 00:15	715	80.6%
Low priority	12 749	00:43 ± 05:58	5998	47.0%
Respiratory rate high	7894	00:17 ± 00:14	3687	46.7%
Pulse oximetry probe off	2723	00:14 ± 00:11	1188	43.6%
Apnoea	680	00:14 ± 00:07	255	37.5%
ECG leads off	495	00:08 ± 00:03	481	97.2%
ECG lead off	261	13:49 ± 31:04	51	19.5%

Note: VT >2, heart rate over 100 bpm in at least three consecutive strokes without persistent tachycardia. Apnoea, no breaths within the preceding 20 s. The default alarm thresholds were: RR High 25 breaths min-1, SpO_2 low 90%, Bradycardia/Heart Rate Low 40 bpm, Tachycardia/Heart Rate High 150 bpm. The priority is assessed by the monitor built-in algorithms (see Methods). Thus, for example SpO_2 low can be categorized as medium or high depending on the alarm parameters.

TABLE 3 Alarm values (initial) and the corresponding number of alarms

Alarm values by alarm type	Number of alarms	Number of momentary alarms	Percentage of momentary alarms
Respiratory rate high (breaths min^{-1})	9077	3939	43.4%
25	657	510	77.6%
26	635	415	65.4%
27	571	362	63.4%
28	510	330	64.7%
29	473	271	57.3%
30	468	248	53.0%
Pulse oximetry low (%)	4572	2264	49.5%
86	238	104	43.7%
87	313	149	47.6%
88	527	222	42.1%
89	803	343	42.7%
90	1618	974	60.2%
Bradycardia (bpm)	1075	895	83.3%
36	98	84	85.7%
37	103	88	85.4%
38	145	117	80.7%
39	112	84	75.0%
40	226	192	85.0%

Note: The default alarm thresholds were: RR High 25, SpO_2 low 90, Bradycardia 40.

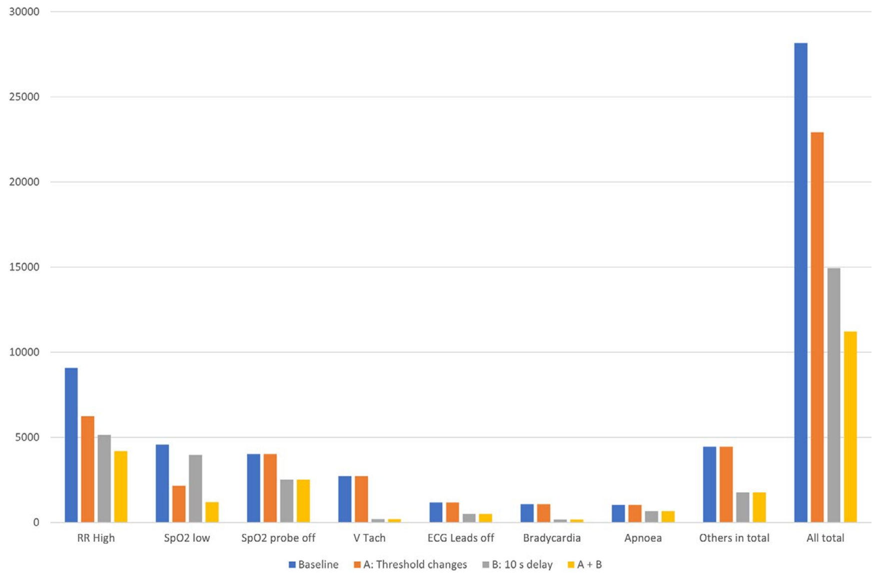

FIGURE 1 Number of alarms before and after hypothetical changes in alarm thresholds and an additional 10 second time delay. V Tach, ventricular tachycardia (heart rate over 100 bpm). Apnoea, no breaths within the preceding 20 s. The default alarm thresholds were: RR High 25 breaths min-1, SpO_2 low 90%, Bradycardia 40 bpm. Effects of threshold changes are estimated only for the RR High and SpO_2 low alarms, with new thresholds for RR High 30 breaths min-1 and SpO_2 low 88%

The potential effects on the number of alarms after a hypothetical introduction of an additional 10 second time delay and a change in the pre-set threshold values of RR high to 30 breaths min^{-1} and SpO_2 low to 88% are shown in Figure 1. The total number of alarms could potentially be reduced by 60.2%, from 28 176 to 11 215.

3.4 | Total sound load

The total number of alarm sounds was calculated based on the priority levels and corresponding sound repetition intervals. We estimated that there were 105 000 alarm sounds produced by the study monitors, 469 alarm sounds per monitor per day. The 12 alarm types with the longest average durations mentioned earlier produced an estimated 59 000 (56%) alarm sounds. Of these, SpO_2 probe off alarm with medium priority produced 44 000 (42%) alarm sounds.

4 | DISCUSSION

The main finding of our study was that the patient monitors produce a substantial amount of alarms. The number of alarms per hour per monitor was 5.2.

Comparison studies have commonly reported their findings as alarms per hour per patient. Based on average monthly patient visits and assuming that a monitor is connected to a patient, except when a change lasting for 1 hour occurs, the number of alarms per hour per patient in our study was approximately 6.3. The corresponding values, as reported by the comparison studies ranged from 2.6 to 7.4 in the studies.[8-11] Our result falls into this range.

We also estimated the total number of individual alarm sounds being 19.5 per hour per monitor and 23.4 per hour per patient. Emergency departments are commonly arranged in such a way that several patients are located in each room and there are several devices attached to patients, that produce alarms. Observation rooms in our study unit were equipped with nine monitors each. As a result, on average there were 176 alarm sounds produced per hour in an observation room. Thus, it is reasonable to state that there is a near-continuous stream of alarm sounds.

One of our objectives was to evaluate alarm fatigue. It is hypothesized that substantial factors leading to alarm fatigue include the large number of alarms, discussed previously, and the poor positive predictive value of the alarms.[2–5] In previous studies in EDs, the correspondence values between patient clinical status and alarms were 75%[10] and 76%.[11] One study revealed that only 0.6% of alarms were triggered due to an adverse event.[9] We could not evaluate the clinical correspondence or significance of the alarms, but we did observe that the number of alarms that were pre-silenced, acknowledged, paused, or led to changes in threshold settings was very low, 2067 (7.3%) alarms together. However, these actions usually co-occurred such that the real number of times when a nurse acted with a monitor was approximately 1000 (3.5%). This is a direct measurement of a nurse acting on a monitor but only an indirect measurement of a nurse acting on a patient. However, this observation was similar to findings of comparison studies that revealed very low percentages of alarms that lead to a change in the clinical management (0.2%[9] and 0.8%[11]). According to the findings of our study and other studies on the high amounts and infrequent management of alarms, we conclude that alarm fatigue is a real and substantial phenomenon in emergency departments.

To reach a satisfying reduction in the number of alarms, actions could be targeted on the most common alarm types, which in our study were RR high, SpO_2 low, SpO_2 probe off, VT, ECG leads off, and bradycardia. One previous study has examined alarm types in an emergency department.[11] Our findings are similar to that study with two exceptions. In the study of Fleischman et al, PVC was the most common alarm type and in our study VT was one of the most common ones. These differences can in part be explained by the fact that the monitors were from different manufacturers and it is also reasonable to assume that majority of the VT alarms in our study were produced by one single patient.

Suggested methods of reducing alarms and alarm fatigue include adjusting alarm thresholds and incorporating time delays.[2-5] In regard to time delays, our results show, that a general additional time delay of 10 s would reduce the total number of alarms by more than 50%. In particular, VT alarms were mostly of limited duration; the average duration was 3 s (±6 s) and 92.2% lasted less than 10 s. However, current industry standards forbid the use of time delays in some ECG-related alarms.[13] Our data show that in the ECG-related alarms, the proportion of momentary alarms was 75%, thus there may be a need to reconsider the restriction on time delays.

In further analysis of alarm durations, we observed that there was a small amount of alarms that sounded for several minutes or even hours before stopping. Together, such alarms were approximately 56% of total alarm sound load. Whether they stopped spontaneously or by intervention of the staff could not be determined. The effects of individual triggered alarms vs the sound load they produce as contributors to alarm fatigue should be studied in more detail in the future. In addition to the more commonly studied time delays, a process whereby an alarm is reacted to within a given time limit would be one approach in reducing alarm sound burden.

As an additional method of reducing the number of alarms, we estimated the effect of changing the pre-set alarm thresholds of the most common alarm types. Our study revealed that changing the thresholds, could reduce those particular alarms as follows: RR high threshold from 25 to 30 breaths min^{-1}, reduction by 31.4%; and SpO_2 low threshold from 90% to 88%, reduction by 53.0%. The overall reduction in the total number of alarms would be 5267 (18.7%). If threshold changes and a 10 s time delay would be combined, we analysed that the reduction in the total number of alarms would not be the pure sum of their effects, but 60.2%, as some momentary alarms are also inside the threshold value. Values presented here are theoretical maximums.

Some notions about the clinical safety of the proposed changes to the alarm thresholds and about the additional 10 s time delay should be provided. First, a survey by AAMI Foundation revealed that the default alarm threshold settings that are in use in emergency departments vary between health care organizations.[14] The threshold ranges, relevant to our study, were for RR high from 24 to 40 breaths min^{-1}, and for SpO_2 low from 87% to 90%. In addition, some organizations used short additional time delays. Second, further implications on safety can be found from studies, that have shown additional time delays from 10 to 15 s, and SpO_2 thresholds from 80% to 85% to be clinically safe settings [15-17] To summarize, we argue that the RR high threshold of 30 breaths min^{-1}, the SpO_2 low threshold of 88%, and a general additional 10-second time delay can be considered clinically safe and would, simultaneously used, significantly decrease the total number of alarms, by up to 60%.

A notable strength of the study is the comprehensive descriptive analysis of the number, types, values, thresholds and durations of alarms. In addition, we estimated the total alarm sound load. These issues are not usually studied in one setting.

There are some limitations in our study. First, as this was a single emergency department study where we selected monitors that were used in observation rooms, the application of the results in other settings is limited. Second, the study was conducted using one type of monitor produced by a single manufacturer and therefore the results may not be generalizable to other types of monitors. One of the major limitations is the fact that from our research data we were unable to evaluate true alarms that required clinical intervention. Since the current hypothesis is that the poor positive predictive value of alarms is a major contributor to alarm fatigue, it would be essential to observe or to otherwise evaluate the clinical interventions made by the staff in response to clinical alarms.

5 | CONCLUSIONS

Alarm sound load, from individual alarm sounds, was nearly continuous in an emergency department observation room equipped with nine monitors. Intervention by the staff to the alarms was infrequent. More than half of the alarms were momentary.

ACKNOWLEDGEMENTS

Assistance with the article: The authors thank Antti Surma-aho and Sari Palojoki for their assistance with this study, and Helena Båtsman for participating in the alarm data collection.

CONFLICTS OF INTEREST

Mr Uutela is working for the manufacturer of the study's patient monitor devices. No other conflicts of interest.

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How to cite this article: Jämsä JO, Uutela KH, Tapper A-M, Lehtonen L. Clinical alarms and alarm fatigue in a University Hospital Emergency Department—A retrospective data analysis. *Acta Anaesthesiol Scand*. 2021;65:979–985. https://doi.org/10.1111/aas.13824