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Prevalence of Alarms in Intensive Care Units, and its Relationship with Nursing Staff Levels

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Abstract

Background: The average number of alarms per patient on each day in Intensive Care Unit (ICU) was very high with poor specificity, high sensitivity and high false positive rate. The large number of false alarms has caused healthcare professionals to turn down the volume of audible signals, adjust the alarm setting beyond limits that are safe and appropriate for the patient, and ignore or even deactivate alarms, resulting in sentinel events and patient deaths. The objectives of the present study were to examine the prevalence of ICU cardiac and technical alarms and the relationship between that prevalence and available nursing staff levels.

Methods: The study collected all cardiac and technical alarm data from the bedside physiological monitor through the central monitoring system at the nurses' station, over a five-week period. The prevalence of these alarms and the correlation with different shifts of duty was analysed. The relationship between nursing staff levels and the number of these alarms was also analysed.

Results: There was a positive correlation between the number of cardiac and technical alarms per bed per hour in three different shifts (Night and Morning, Morning and Afternoon, and, Afternoon and Night: All p-value<0.001). The effect of these alarms on the present shift will affect the number of alarms in the subsequent three shifts. Besides, the number of cardiac and technical alarms is not related to the nursing staff levels.

Conclusions: This study describes the prevalence of cardiac and technical alarms from a different perspective, by examining the prevalence of physiological monitor cardiac and technical alarms in ICUs (but not their sound amplitude) and its relationship with nursing staff levels, the finding against many people thinking that the cardiac and technical alarms should be fewer when the nursing staffing level is high in the unit.

Keywords: Alarm fatigue; Alarm fatigue nursing; Intensive care unit; Staffing levels

Introduction

Alarm devices are designed to alert healthcare professionals to any change in the condition of patients in their care. This is especially important for ICU staff, as a patient's condition may change very suddenly and require an immediate response on their part. However, the average number of alarms per patient on each day can be over 900, or one critical alarm every 92 seconds [1], and over 40 different devices may be operating at the same time [2]. Although there are a large number of alarms per patient per day, they do not all require clinical action. Experts estimate that between 85% and 99% of alarm signals do not warrant clinical intervention, with one study, in an emergency department, reporting that fewer than 1% of alarms were clinically actionable, requiring bedside intervention [3,4].

To prevent clinically relevant patients events being missed, the design of the monitor system usually involves high sensitivity, poor specificity and a high false positive rate [5,6]. Worse, there is no standardisation of alarm sounds and their decibel levels [4]. Studies have indicated that the noise level in ICUs already exceeds International Noise Council and World Health Organisation recommendations [7,8], and that hospital noise levels have increased by 0.38 dB/year during the day and 0.42dB/year at night [8]. The large number of false alarms has caused healthcare professionals to turn down the volume of audible signals, adjust the alarm setting beyond limits that are safe and appropriate for the patient, and ignore or even deactivate alarms, resulting in patient deterioration and deaths [9]. The patient's physiological condition may also be affected, as studies have shown a positive correlation between hospital noise and physiological responses, such as tachycardia and stress experienced by patients [8]. The Emergency Care Research Institute (ERCI) defined this as a condition of sensory overload for staff, who are exposed to an excessive number of alarms and suffer from what it called 'alarm fatigue' [10]. The Joint Commission also established the 2014 National Patient Safety Goal (NPSG) on clinical alarm safety to help hospitals begin to identify the most important alarm and make it a priority by July 1 2014. In addition, from January 1 2016 hospitals will be expected to develop and implement policies and procedures for managing alarms and to instruct staff on the purpose and proper operation of the alarm systems for which they are responsible [9]. While NPSG is a US based commission, but the issues of alarm safety should be addressed wherever there is a clinical area where potential alarm fatigue will happen. In Hong Kong, there are 15 ICUs across the city and the total

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number of ICU bed is over 200. Hence we may expect the same alarm issues and fatigue will also happen in ICUs of Hong Kong.

There have been numerous studies of the noise levels in hospital ICUs. A recent review article analysed 29 studies related to noise in ICUs, and found they used inconsistent methodologies with poorly defined parameters that made it difficult to compare results [8]. The most common parameter that these studies used was the amplitude in decibels, with medical equipment alarms being one of the sounds that many studies refer to. The present study, however, describes the prevalence of cardiac and technical alarms from a different perspective, by examining the prevalence of physiological monitor cardiac and technical alarms in ICUs (but not the sound amplitude) and its relationship with nursing staff levels.

The objectives of the present study were to examine the prevalence of ICU cardiac and technical alarms and the relationship between that prevalence and available nursing staff levels. The hypothesis is the prevalence of ICU cardiovascular and technical alarm will negatively associated with the nursing staff levels. Since it only involved cardiac and technical alarm systems, the institutional review boards of the Hospital Authority's Hong Kong West and New Territories West Clusters waived any requirement for ethical approval.

Methods

The study collected all cardiovascular and technical alarm data from the bedside physiological monitor through the central monitoring system at the nurses' station, over a five-week period. The study site was a 14-bed general ICU, catering for medical, surgical and trauma patients, in the Western area of Hong Kong. The annual turnover of patients was 2,000 in 2013, making it one of the biggest ICUs in the territory.

In order not to affect the routine laboratory results printing at midnight and many nurses will use the printer to print out discharge summary or other clinical notes at daytime, the data collection start at 4am, which is the least printer usage time in the study unit. The data collection period ran from 4am on 25 September to 4am on 30 October 2014. Through the setting of the central monitoring system, at every 4am each day, the past 24 hours' cardiovascular hourly alarm data (red–high priority, yellow–medium priority) and technical hourly alarms from the bedside physiological monitors within the unit was printout automatically at the nurses' station. The raw data then enter by the investigator into the Microsoft Excel and imported into SPSS V. 23 for analysis. For those beds didn't occupied by patient during a particular hour and hence no alarm will be generated, it was exclude from the calculation for the number of alarm per bed per hour at that particular hour. High priority, medium priority and technical alarms being defined as follows (Table 1):

- High priority: indicates a high-priority patient cardiac alarm and a potentially life-threatening situation (for example, a systole).
- Medium priority: indicates a lower priority patient cardiac alarm (for example, a paroxysmal supraventricular tachycardia).
- Technical: also called bed alarms or technical alerts, these indicate that the monitor cannot measure or detect alarm conditions reliably (for example, ECG leads off, SpO2 no pulse, noninvasive blood pressure bladder overpress and bladder not deflating).

Type of alarm	Details
High priority	Ventricular tachycardia>100 beats/min and ≥ 5 Premature Ventricular Contraction (PVCs)
	Ventricular fibrillation / tachycardia
	Asystole>4 seconds
	Extreme tachycardia>140 beats/min
	Extreme bradycardia<40 beats/min
Medium priority	Supraventricular tachycardia (SVT)>180 beats/min and ≥ 5 Supraventricular Beat (SVBs)
	Ventricular rhythm>14 PVCs
	Run PVCs>2 PVCs
	Pair PVCs
	R-on-T PVCs
	Ventricular bigeminy
	Ventricular trigeminy
	PVCs rate>10 PVCs/min
	Multiform PVCs
	Pacer not captured
	Pacer not pacing
	Pause>2 seconds
	Missed beat
	Non-sustained ventricular tachycardia
	Irregular heart rate

Table 1: The default arrhythmia parameter settings used in the study site.

According to unit policy, all nurses need to perform an initial assessment of the patient under their care for that shift of duty and to set the cardiac alarm limits at plus or minus ten percent of the assessment readings. However, they are not allowed to change the default unit's arrhythmia and technical alarm settings, that is, the high priority and medium priority alarms described below.

A similar study of prevalence and alarm interventions was conducted in 2006 [1], the nature and scale being comparable to those of the present study site. We therefore adopted a similar time frame to that study and used the data from 35 days to examine the prevalence of alarms.

The primary outcome was the number of cardiac and technical alarms from bedside physiological monitors, expressed as numbers per bed per hour. The secondary outcome was the relationship between nursing staff levels and alarm (cardiac and technical) prevalence.

Data Analysis

Data analysis includes descriptive statistics of the number of cardiac and technical alarms (mean and SD) and their distribution in order to explore any particular period of time when these alarms were more

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frequent. Through inferential statistics, bivariate correlations were performed to explore the relationship between the numbers of cardiac and technical alarms per bed per hour in different shifts. The duration of shifts is: Morning: 0700 to 1400, Afternoon: 1400 to 2100 and Night: 2100 to 0700 next day. Morning and afternoon shifts have higher nursing staff levels, with a nurse-to-patient ratio of approximately 1:1, while during the night shift the ratio is cut to a maximum of 1:2, or even less.

Percentage of total daily monitor cardiac and technical alarms distribution among different shifts per day and the mean number of cardiac and technical alarm per bed plotted against time were perform to explore any particular period of time when cardiac and technical alarms were frequent, and any particular trend of these alarms across the day. Besides, number of cardiac and technical alarms per bed per hour during different shift across a day will plot again each day to look for any autocorrelation of these alarms between two or more consecutive shifts. If we found the number of cardiac and technical alarms increased or decreased in the same way during all three consecutive shifts, e.g. if there was an increase in the number of cardiac and technical alarms in the Night shift, the number in subsequent Morning and Afternoon shifts would also increase. The number of shifts with this effect was calculated by the auto-correlation function (ACF).

ANOVA tests were performed to look for any obvious differences in the number of cardiac and technical alarms per bed per hour over the day and the effect of nursing staff levels during breakfast, dinner and the night shift, when only have half as many nurses were present in the unit. Post-hoc testing was performed if the ANOVA tests showed statistically significant results in order to find the difference was between which shifts. All analysis was performed by means of SPSS V23.

Results

Prevalence of alarms

The means of high priority, medium priority and technical alarms per hour were 3.95 (SD=12.22), 14.71 (SD=14.71) and 14.22 (SD=24.79), respectively, yielding mean total numbers of alarms (high priority, medium priority + technical) per hour and per bed per hour of 51 (SD=40.41) and 5.35 (SD=3.82), respectively.

Trend of alarms and relationship of total number of alarms (cardiac and technical) between different shifts

In order to explore whether there was any particular period of time when cardiac and technical alarms were more frequent, and any particular trend of cardiac and technical alarms across the day, the total number of cardiac and technical alarms per bed per hour was plotted against time, as shown in Figures 1-3. In Figures 1 and 2, there was no obvious trend, nor any particular time of the day when cardiac and technical alarms per bed per hour were more frequent. However, we suspected from observation that the number of cardiac and technical alarms might be affected by the shift immediate before current shift or even earlier shift and cause what we called auto-correlation, as the number of cardiac and technical alarms per bed per hour for the three different shifts moved in the same direction within the day (Figure 3). Since the same group of patients may well have remained in the unit over two or more consecutive shifts, the number of cardiac and technical alarms per bed per hour during a subsequent shift would be affected by the previous or even earlier shift if the combination of patients had not changed very much during the day and this maybe the reason for this auto-correlation.

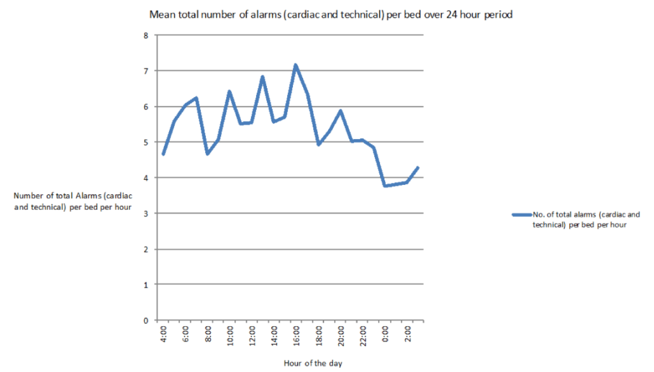

Figure 1: Mean total number of alarms (cardiac and technical) per bed over 24-hour period.

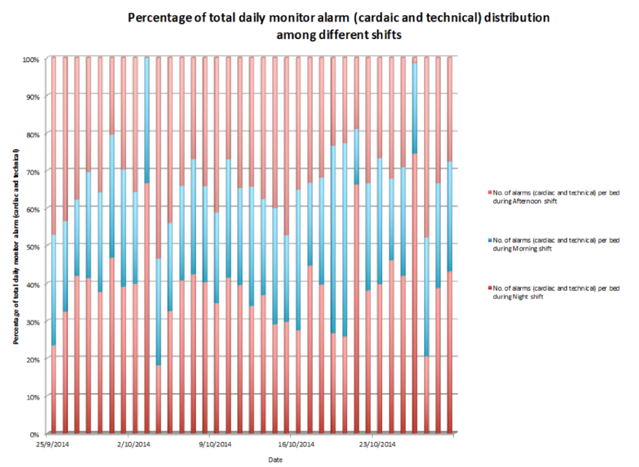

Figure 2: Percentage of total daily monitor alarms (cardiac and technical) distribution among different shifts (morning shift, afternoon shift and night shift).

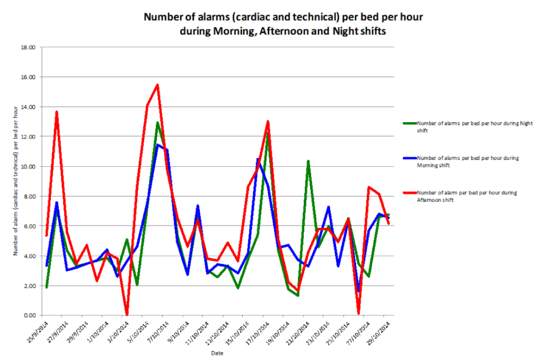

Figure 3: Number of alarms (cardiac and technical) per bed per hour during morning shift, afternoon shift and night shift.

Bivariate correlation was employed to test for any correlation between the alarm (cardiac and technical) frequencies of different shifts. The result shows a positive correlation between the numbers of alarms (cardiac and technical) per bed per hour in three different shifts (Night and Morning: p-value<0.001; Morning and Afternoon: p-value<0.001; Afternoon and Night: p-value<0.001). ANOVA was performed to test for any significant difference between the three different shifts in the number of alarms (cardiac and technical) per bed per hour, but the results showed no statistical difference (p-value=0.063), which means the number of cardiac and technical alarms were very similar among three different shift. The auto-correlation function (ACF) was calculated by using lag=25 as suggested by other journal article (n/4, where n is the total number of shift during the study period) [11]. The results showed the first three lags with values outside the confidence limits, with ACF=0.564, 0.465 and 0.333 (SE: 0.096, 0.096 and 0.095, p-value<0.001), which means if there was an increased number of cardiac and technical alarms during the night shift it would be followed by similar increases in the subsequent morning, afternoon and night shifts.

Relationship between prevalence of alarms and nursing staff levels

The study hypothesis is the prevalence of ICU cardiovascular and technical alarm was negatively associated with the nursing staff levels. That means, the number of cardiac and technical alarms per bed per hour will increase when the nurse to patient ratio was lower, i.e. at breakfast (0700-0900) and dinner (1800-2000) times, when half the staff would go for their meal, and during the Night shift, when the nurse to patient ratio was down to 1:2 or even less. ANOVA was employed to test for any statistical difference between full nursing staff levels (daytime excluding mealtimes), low levels during mealtimes, and low levels during the night shift. The results showed there was indeed a statistical difference between different nursing staff levels (p-value=0.003), which means the total number of cardiac and technical alarms associated with the nursing staff levels. Post-hoc tests (Tukey HSD) of different staffing levels across the day were performed, and showed a statistically significant difference between full levels (daytime excluding mealtimes) and low levels during the night shift (p-value=0.002, 95% C.I.=-2.096, -0.444).

Discussion

A. Prevalence of cardiac and technical alarms

The number of cardiac and technical alarms per bed was 5.35 per hour or 128.4 (5.35x24) per day, less than in a previous study (350 alarms per patient per day) (9). Since the study site was an ICU, where the most severely affected patients were to be found, with the most monitoring systems and medical equipment around them compared with other units in the hospital, the high number of alarms was to be expected. One cause of this lower number of alarms might be the types of alarm being counted. In this study, because of the limitations of the system software, only cardiac-related and technical alarms (high priority, medium priority and technical) could be collected for analysis, while other studies were able to collect other types of alarm, such as those monitoring respiratory rate, SpO_2, arterial blood pressure and certain other parameters. It is this that is likely to have caused the substantial difference in the number of alarms.

B. Trend of cardiac and technical alarms and relationship of total number of alarms (cardiac and technical) between different shifts

Figures 1 and 2 shows no obvious difference in the number of cardiac and technical alarms per bed per hour over a 24-hour period. However, it was observed that the number increased or decreased in the same way during all three consecutive shifts, e.g. if there was an increase in the number of cardiac and technical alarms in the Night shift, the number in subsequent Morning and Afternoon shifts would also increase. The bivariate correlation test showed there was a positive correlation in the number of cardiac and technical alarms per bed per hour during three different shifts, with all three combinations: Night & Morning, Morning & Afternoon, and Afternoon & Night showing a statistically significant difference, with a p-value <0.001. That means, if the number of cardiac and technical alarms per bed per hour increase in current shift, the number of cardiac and technical alarms will also increase in subsequent shift. The subsequent ANOVA test also showed there was no statistical difference among all day shifts (p-value=0.063), proving that the positive correlation between two subsequent shifts was very significant in respect of the number of alarms per bed per hour, which means the number of cardiac and technical alarms were very similar among three different shift.

The auto-correlation function (ACF) also produced statistically significant results (p-value<0.001) for three consecutive lags of shift duty, meaning that if there was an increased number of cardiac and technical alarms during the night shift it would be followed by similar increases in the subsequent morning, afternoon and night shifts (ACF=0.564, 0.465 and 0.333). One of the reasons for the positive correlations between different shifts in the number of cardiac and technical alarms per bed per hour might have been the fact that the same patients (or the majority of them) stayed in the unit, with only a few being discharged to a general ward each day. According to the hospital records, the number of patients discharged from the ICU during the study period averaged two (out of 14) per day (range 0–4). This implies the combination of patients would not change very much from one shift to the next, and the same or a similar group of patients would generate a similar number of cardiac and technical alarms. However, we cannot conclude that all the patients in the ICU at any one time will be discharged to a general ward after three consecutive shifts and the number of alarms (cardiac and technical) no longer correlated with the previous or subsequent shift as we do not know whether the auto-correlation effects tailing off after three shifts is due to changes in the mix of patients or to their condition improving and thus triggering fewer cardiac and technical alarms.

Since both patients and nurses benefit from consistency, assigning a bed with a large number of cardiac and technical alarms to different nurses each shift in order to avoid persistent exposure to high cardiac and technical alarm levels by the same nurse might not produce any actual benefits in patient care. We suggest a more flexible customised alarm system should be introduced to reduce the number of false or non-actionable cardiac and technical alarms. In the long run, default arrhythmia alarm settings should be reviewed regularly in order to meet the needs of the patient.

C. Relationship between prevalence of alarms (cardiac and technical) and nursing staff levels

One factor concerned with the number of cardiac and technical alarms was the effect on nursing staff levels. We assumed higher levels during the day would mean fewer cardiac and technical alarms, as nurses could respond to patients' needs or correct any technical problems immediately. This was especially true in the case of technical alarms, as these are related to technical issues where the physiological monitor cannot perform its work properly and require staff to attend to the problem, e.g. ECG leads disconnected. The ANOVA test showed there was a statistically significant difference between full and partial nursing staff levels where the number of cardiac and technical alarms per bed per hour was concerned (p-value=0.003). Subsequent post-hoc testing (Tukey HSD) showed that the difference was between the night and daytime shifts, the latter with a full nursing staff on duty (excluding the periods when half the nurses were having their breakfast or dinner) (p-value=0.02, 95% C.I. -2.096, -0.444). The results showed that cardiac and technical alarms were less frequent when staff levels were lower, such as during the night shift – which conflicts with our assumption that cardiac and technical alarms should be more frequent when there were fewer nurses on duty. One of the reasons might be related to the fact that many patients were asleep at night and hence there was less body movement which might indirectly affect the number of technical alarms by making triggering the technical alarm less likely, in cases such as ECG leads or Sp02 probes being off. In order to prove this assumption, we further analysed the data by running ANOVA tests for three different types of alarm per bed per hour (high priority, medium priority and technical) at different nursing staff levels. The results showed no difference in the number of high priority and medium priority alarms at different staff levels (high priority: p-value=0.179; medium priority: p-value=0.214), but did indicate a difference in the case of technical alarms (p-value=0.001). The post-hoc (Tukey HSD) test showed there was a difference in the number of technical alarms per bed per hour between the night and daytime (full staff) shifts, again excluding mealtimes (p-value=0.001, 95% C.I. -54.53, -15.17). The number of alarms during the night shift differed significantly from that in the fully staffed daytime period, while having fewer technical alarms. High priority and medium priority alarms are triggered by a patient's intrinsic heart condition, such as life-threatening asystole or a lower priority cardiac condition such as paroxysmal supraventricular tachycardia (PSVT), and will not therefore be affected by the patient's movements during day or night.

Limitations of the Study

The system software limited the types of alarm that could be covered and many types of alarm could not be recorded in this study, restricting comparisons with other published studies and possibly underestimating the number of ICU alarms. In addition, the study site hospital also had a coronary care unit (CCU) and many patients with heart problems were likely to be admitted there instead of the ICU, further lowering the number of cardiac alarms (high priority and medium priority), being recorded. Another limitation is that the study did not consider the severity of the patient's condition by collecting an APACHE score - we expect that the more critical a patient's condition is, the more cardiac alarms will be recorded. This makes a comparison between the present study and others difficult, as some of other studies were conducted in a university hospital's ICU, where the severity of the patient's condition when admitted and nursing staff levels may be different. Additionally, the study did not review any reports of sentinel events, which may cause patient deterioration, and patient deaths that occurred during the study period. As a result, we cannot be sure whether or not such factors as reducing audible alarm levels or changing alarm limits beyond those considered safe and appropriate for the patient, or ignoring or even deactivating alarms were associated with or related to sentinel events and patient deaths. Finally, the study did not collect the number of staff per shift, restricting the estimation of the total number of cardiac and technical alarms need to face per nursing staff in a shift.

Conclusion

This study describes the prevalence of cardiac and technical alarms from a different perspective, by examining the prevalence of physiological monitor cardiac and technical alarms in ICUs (but not their sound amplitude) and its relationship with nursing staff levels, adding certain facts to the present body of knowledge about ICU cardiac and technical alarms that the number of alarms is not related to the nursing staff levels during the day and the number of alarms during the night shift is less than in the day, despite the staff level being 50% less. The finding against many people thinking that the cardiac and technical alarms should be fewer when the nursing staffing level is high in the unit. Currently, despite many articles mentioning the importance of 'alarm fatigue', there is still no research or study on what the threshold is where the number of alarms will cause healthcare workers to develop such fatigue. Further research is recommended to establish this threshold and inform both healthcare staff and hospital management.

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