Alarms on the Intensive Cardiac Care Unit

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Abstract

Patients admitted to the Intensive Cardiac Care Unit are closely monitored by different devices that generate alarms when an abnormality is detected. However, most alarms do not signify a life-threatening event. During a four month period 34,827 alarms were collected electronically. The most frequent alarm categories were related to mechanical ventilation (42.2%), blood pressure (32.3%), electrocardiogram (9.8%) and heart rate (8.1%). 2750 (7.9%) of the alarms were not related to limit violations, but were technical advisories. Overall alarm frequency was 2.2 per patient per hour. However, the distribution over time varied greatly and alarm "bursts" were seen when blood samples were taken and patients were woken. Reduction in alarms could be achieved by reducing overuse of monitoring parameters, utilizing patient specific limits and combining alarms within the "bursts".

1. Introduction

Patients admitted to the Intensive Cardiac Care Unit (ICCU) are closely monitored by different devices. When an abnormality is detected, an alarm is generated. Alarms can be categorized as a limit violation or as an advisory message. Limit violations occur when a (physiological) parameter exceeds a pre-defined value (for example a high heart rate), advisory messages indicate a technical problem (for example a lead disconnection) or a medical situation requiring action (such as an empty syringe in an infusion pump). Alarms are further classified according to urgency [1]. A high priority alarm indicates a critical situation requiring immediate response; medium priority indicates a dangerous situation requiring urgent, but not immediate response; low priority alarms require attention, but not immediately. Default alarm settings are set up by the manufacturer to maximize sensitivity, at the cost of a high false positive rate [2]: most alarms do not signify a life-threatening event.

The reported frequency of alarms in the intensive care environment ranges from 1.6 [3] to 14.6 [4] per hour with a false alarm rate of up to 91% [5]. Approaches to improving alarm accuracy have been described [6-8], however implementation is limited. Current patient care devices allow the electronic transmission of alarms to a central gateway [9] and may facilitate the implementation of certain strategies to improve alarm accuracy.

The aim of this study was to evaluate the distribution over time and by category of electronically collected alarms on the ICCU, and to describe how this information could be used to reduce frequency and improve the accuracy of alarms.

2. Methods

From 17 December 2008 through 16 April 2009 alarms from the 8-bed ICCU at the Erasmus Medical Center, Rotterdam, Netherlands, were received from the patient monitoring network [9]. The intelligent Patient Universal Tele Alarm (i-PUT) [10], an open source toolkit was used to collect the alarms from the network and store them in a SQL database for analysis [11].

Devices hooked up to the monitoring network included blood pressure, hemodynamic and oxygen saturation monitors as well as mechanical ventilators. Alarms generated by infusion and feeding pumps, dialysis and circulatory assist devices, air mattresses and other patient care devices were not analyzed as they were not hooked up to the monitoring gateway.

The alarms were categorized by type and urgency based on the information received from the gateway. The number of alarms was determined for each hour during the study period. The number of alarms was compared for: nighttime hours (0.00-6.00) vs. daytime, weekday vs. weekend and hours with extra activity vs. the other "normal" hours. Extra activity was present from 6.00-7.00, when patients were awakened and blood samples were drawn, and from 8.00-10.00 when patients were washed.

Student's t-test (SPSS version 12) was used to evaluate differences in hourly alarm rate between categories. Continuous data is displayed as mean ± SD or median (IQR) as appropriate. A P-value of <0.05 was considered statistically significant.

3. Results

Over the four month period 34,827 alarms were collected during 547 patient admissions with a duration of 6.1(3-23) hours.

The most frequent alarm categories are displayed in Table 1 and were related to mechanical ventilation (42.2%), blood pressure (32.3%), electrocardiogram (9.8%) and heart rate (8.1%). 2750 (7.9%) of the alarms were not limit violation alarms, but technical advisory messages. Main causes of these advisory messages were: ECG artifacts (64.9%), disconnected devices (29.3%) and SpO2 artifacts (2.9%).

Alarm type	%	n
Respiratory	41,2%	14357
Blood pressure	32,3%	11249
Electrocardiogram	9,8%	3430
Heart rate	8,1%	2822
Advisory	7,9%	2750
Temperature	0,3%	121
Left atrial pressure	0,1%	49
O2 saturation	0,1%	49
Total	**100,0%**	**34827**

Table 1: Distribution of alarms by type

The median alarm frequency was 9 (5-18) for the ICCU per hour (on average 2.2 per patient per hour). The number of alarms per hour on the ICCU is displayed in Figure 1. There was overall decreased alarm frequency during night-time (0.00 until 6.00) when compared to day: 7 (3-13) vs. 11 (5-19) per hour (P<0.001).

A peak in alarm frequency was seen at the time of drawing blood samples from the arterial line and awakening of the patients. Another peak occurred between 8.00 and 10.00 when patients are washed. The alarm frequency during these peaks was 17 (8-26) per hour vs. 9 (4-16) during other hours (P<0.001). There was no difference in frequency of alarms by day of week.

The time between alarms varied greatly with a median of 1.3 (0.5-4.1) minutes, mainly due to the occurrence of alarm "bursts": in 50% of the alarms the interval was less than 90 seconds. The skewed distribution of the alarm intervals is apparent in the histogram in Figure 2: note that the time interval is a logarithmic scale.

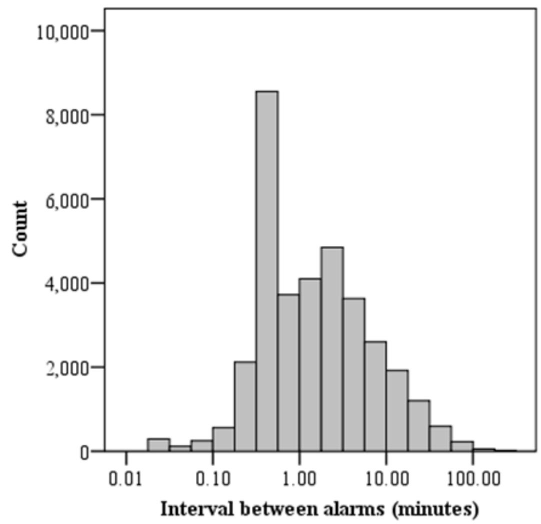

Figure 2: Histogram of the time inbetween ICCU alarms.

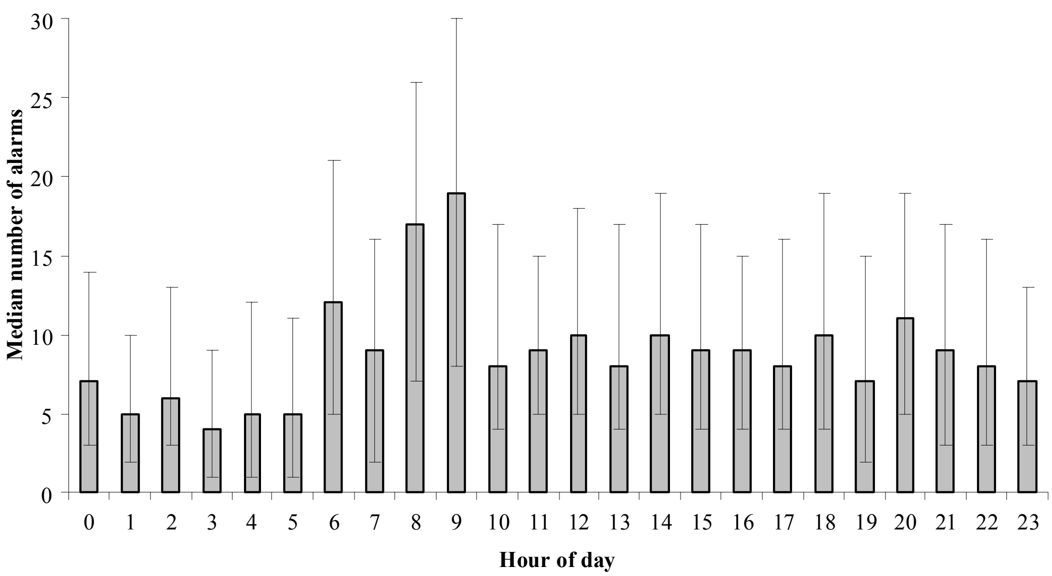

Figure 1: Median number of alarms on the ICCU per hour. Error bars indicate the IQR.

4. Discussion

The current study evaluated frequency of alarms received electronically by a central gateway and included alarms generated by blood pressure, electrocardiogram, O2 saturation and respiratory therapy patient care devices.

The mean daily number of alarms per bed in the current study was 37±22, which is similar to the 39 reported by Chambrin et al. [3] in a general intensive care unit. Additionally, they also reported a lower frequency during the night-time shift.

Siebig et al. [12] evaluated the differences in alarm distribution between the different intensive care units of the same hospital, and found them to be similar. They did not find a difference in alarm frequency related to time, and reported a higher rate of 4.3 alarms per patient per hour, even though they did not include respiratory alarms. Alarm settings, but also a different collection method (using a custom program to extract the alarms from the monitors) may explain the higher frequency.

The lower frequency of alarms during night-time in the current study may be due to less patient activity and less planned procedures.

In the current study, the distribution of alarms over time varied greatly due to the occurrence of alarm "bursts". There are several explanations for this clustering.

First, in the case of a true critical event, many monitored parameters are likely to change simultaneously or sequentially within a short time period, as they are physiologically linked, and would generate alarms as their limits are violated.

Second, in the case of a procedure, artifacts of different monitoring parameters may be generated within a short time period; the nurse may draw blood from the arterial line, generating several alarms from the invasive blood pressure monitor, and may suction the airway, causing respiratory alerts.

Third, during the admission or discharge of a patient, many alarms are generated as the patient is hooked up to or disconnected from the different monitoring devices.

Lastly, it can be expected that a random distribution of the events comes with a random, and thus unequal distribution over time.

To reduce the frequency and improve the accuracy of alarms, different strategies have been described.

Most importantly, for each patient, the necessity of monitoring should be evaluated for each parameter, based on the patient specific risk profile [13].

Further, appropriate adjustment is needed for the limits of the parameter. Additionally, alarm settings should be dealt with appropriately before performing a procedure [6]. User knowledge on how to do this is necessary, and may be aided by uniform interfaces on devices from different manufacturers. This could reduce the higher frequency of alarms seen during hours of blood drawing and patient washing.

Also, utilizing patient care device "intelligence" may improve the accuracy of the alarms. Different strategies have been described [7,14], and include the use of trends, combining information from different channels within the device, and automated setting of limits.

However, though these strategies are necessary to reduce the frequency and improve the accuracy, they may not be sufficient on their own.

In the future, the number of patient care devices is likely to increase, and to successfully implement intelligence, devices will need to have access to information obtained by other devices (eg. in the absence of a signal, an electrocardiographic monitor could send a disconnect alert rather than an asystole alarm if it knows that there is a heart rate detected by a different patient care device).

Additionally, the alarm needs to be delivered to the appropriate caregiver. This concept becomes more important as patients are cared for in individual rooms, sometimes in isolation: audible alerts generated by a patient care device are only noticed when the caregiver is in the room.

The current study demonstrates that it is feasible to collect alarms electronically from different monitoring devices. I-PUT [10], the platform used, provides a starting point for reducing alarm frequency.

First, it can be used to evaluate the effect on alarm frequency of user targeted interventions to improve utilization of monitoring and alarm limit settings.

Second, i-PUT can be used to generate 'smart alarms'. Alarm data can be sent to a third party decision rule engine, such as GASTON [15]. A clinician or nurse can then design decision rules using the alarms from i-PUT to aggregate and process information from multiple alarms into 'smart alarms'.

Finally, i-PUT can provide output to different modalities, such as paging, but also SMS and web-based devices. Thus, different strategies can be applied to optimize the delivery of alarms to the caregiver.

4.1. Limitations

The current study evaluated alarms generated by patient care devices hooked up to a monitoring network. Other patient care devices such as infusion and feeding pumps, patient beds, dialysis and circulatory assist devices, and others may also be hooked up to a patient, and may contribute significantly to the alarm load. However, it is unlikely that the alarm trends from other devices are much different from the current analysis.

There may be a slight discrepancy between the audible alarms and the alarms collected in the current study; given certain circumstances, a device may generate an alarm to the gateway without producing an audible alert. The goal of the current study was to investigate how electronically collected information could help reduce the alarm frequency; however this issue needs to be addressed when implementing a solution.

The current study did not investigate the accuracy of the alarms. Previous studies in intensive care settings have shown that alarms in an intensive care setting have a low specificity [3-5,16]. The occurrence of bursts related to hours of increased activity suggest that there may be more false positives during these periods. However, prospective evaluation is necessary to confirm this.

5. Conclusions

Alarms on the ICCU were unequally distributed over time: increased frequency was seen during hours with extra activity and during daytime.

Electronic collection of alarms is feasible, can facilitate the evaluation of user targeted interventions to reduce alarm frequency, and when combined with a rule-engine, could combine data from different monitoring devices to generate “smart alarms”.

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