Review

Alarms in the intensive care unit: how can the number of false alarms be reduced?

Marie-Christine Chambrin

University of Lille, Lille, France

Correspondence: Marie-Christine Chambrin, chambrin@lille.inserm.fr

Published online: 23 May 2001
Critical Care 2001, **5**:184–188

Abstract

Many alarms, as they now exist in most monitoring systems, are not usually perceived as helpful by the medical staff because of the high incidence of false alarms. This paper gives an overview of the problems related to their current design and the objectives of monitoring. The current approaches used to improve the situation are then presented from two main standpoints: organizational and behavioural on the one hand, and technical on the other.

Keywords critical care, false alarm, patient monitoring

Many alarms, as they now exist in most monitoring systems, are usually perceived as unhelpful by medical staff because of the high incidence of false alarms; that is, alarms with no clinical significance.

This paper gives an overview of the problems related to the current design of alarms, and the objectives of monitoring. The current approaches used to improve the situation are then presented from two main standpoints: organizational and behavioural on the one hand, and technical on the other. 'Organizational' refers to the definition of a compromise between the use of heavy monitoring that induces many false alarms and the use of light monitoring that can lead to the tardy detection of an adverse incident. This orientation is approached through recommendations such as those published by the learned societies. The other standpoint concerns the development of technical solutions: improvement in the technology of some sensors to reduce artifacts, and the use of multiparametric analysis to reduce the number of false-positive alarms.

Objectives of the monitoring

Alarms are currently generated on crossing a limit. This notion of limit is of course useful in determining physiological limits of variation of a parameter but it is probably not the best method of event detection. The information that the clinician wants most of the time is the detection of relevant abnormalities or changes in a patient's condition. This is not easily reflected in a value crossing a limit but rather by the simultaneous evolution of different parameters. We face a problem that is not merely technical but involves the function and objectives of monitoring. A very interesting review of goals and indications for monitoring is presented by Pierson [1]. He recalls a definition of monitoring given by Hudson: "Monitoring is making repeated or continuous observations or measurements of the patient, his or her physiological function and the function of life support equipment, for the purpose of guiding management decisions, including when to make interventions and assessment of those interventions". The physiological function is supposed to be monitored through physiological parameters that reflect that function more or less precisely. Monitoring then serves the purpose of maintaining a parameter within 'normal' values. In practice, we can observe wide variations in a given parameter without alteration of the physiological function. That is what is generating false alarms: in spite of being true for the monitoring device (the parameter did cross the limit) they have no clinical significance. Several studies in paediatric and adult critical care

Ptc_{O2} = transcutaneous partial pressure of O_2; Sp_{O2} = saturation of oxyhemoglobin determined by pulse oximetry.

units have been conducted to examine the relevance of alarms in monitoring; they showed that less than 10% of alarms do induce a therapeutic modification [2–4]. However, Tsien [3] mentioned that "not a single false negative alarm was recorded on 298 monitored hours". The same thing was observed by Lawless [2] and Chambrin [4] studies (respectively 928 and 1971 monitored hours). The fact that no major event that was related to worsening of the patient's status occurred without previous alarm suggests that the current monitoring is effective in detecting vital problems, but its low specificity might lead to several adverse consequences. Alarms produce noise louder than 80 dB that can lead to sleep deprivation [5,6] and continuous stress for both patients and staff [7,8]. Such a constant demand may result in nurses delaying their intervention, trying to recognize life-threatening alarms by sound only. A study demonstrated that experienced nurses are able to recognize only 38% of vital alarms [9]. This practice could therefore have severe consequences when the patient's condition is deteriorating. Different approaches have been used to improve the situation.

Alarm generation and management

Currently available monitoring systems provide for the setting of an alarm on most physiological data. This creates a great number of potential alarms. Thus, it is possible to count more than 40 alarm sources, taking into account ventilation data, electrocardiogram, arterial pressure and pulse oximetry for a patient undergoing mechanical ventilation. Alarms generated by the perfusion pump, the nutrition pump, the automatic syringe and the dialysis system, among others, must be added to this list. The present technique used to generate an audible alarm signal is based on setting a threshold. For every parameter, the trigger of the alarm is set off immediately if its value reaches the limit or in some cases when its value has been beyond the limit for a given time. On the same monitoring system, when the values of several parameters are beyond the limit, an audible signal is triggered on the first parameter that reached the alarm threshold; alternatively there can be a hierarchy of alarms. In all cases it is necessary to set the threshold alarm limit.

There is no standard for default alarm setting. For a given parameter, this default setting can vary from one monitoring system to another [10]. In some cases, the last settings are taken into account as defaults for the new use of the monitoring system. At least some systems provide a procedure for determining the initial value from an initial record of the parameters.

The priority in alarm management is first to recognize and locate the source of the alarm and then to attribute a significance to this alarm. For an experienced user, locating the alarm is facilitated by the different sounds produced by the equipment. What is bothersome is the repetition and loudness of the alarms. Analysing the significance of the alarm for the patient remains as the major difficulty.

At present, all available monitors provide reliable information both on the value of a given parameter and for the recognition of some events. An alarm event in a cardiovascular monitor can be a technical defect, such as a bad electrode position, or a high level of signal interpretation, such as an arrhythmia. The problem is no longer purely at the level of signal analysis but at the level of management of the data for alarm generation. At present, audible alarms are generated only on a limit value, whatever the data are: there is no gradation related to the degree of urgency. For example, a disconnection of the patient from the ventilator produces the same audible alarm as a high level of minute ventilation. In the first case, the alarm is vital for the patient and independent of any setting. The second case could be related to the setting of the ventilator and is not immediately prejudicial to the patient.

Standards and recommendations

This concept of urgency has been adopted by several committees for normalization that define standards for medical devices, in respect of electrically generated alarm signals. For example, the European Committee for Standardization (CEN: Comité Européen de Normalisation) has established a classification of the alarms in three categories [11]: high priority, indicating an urgent situation (one that can lead immediately to a vital problem; this requires an immediate response from the medical staff); medium priority, indicating a dangerous situation (a quick response from the medical staff is needed); and low priority, indicating an alert situation (the attention of medical staff is needed). A precise description of the signal composition is given in terms of its characteristics in time and frequency according to the level of priority, resulting in a sequence of notes in a distinctive rhythm for each level. However, this standard gives no indication of the conditions required to produce an alarm of a given priority. This information is given in other standards related to specific medical devices.

For example, according to the standard corresponding to the ventilator [12], alarms of high priority are those related to electrical or pneumatic failure, or high airway pressure. Disconnection, apnoea, low expiratory minute ventilation or high or low concentration of dioxygen during inspiration are considered to be alarms with at least a medium priority. This notion of vital alarm is also described by Sanborn [13], who mentions that only ventilator failure, disconnection and obstruction require immediate intervention and then should require an audible alarm.

In the standard related to capnography [14], it is specified that when a capnograph is used with an objective of monitoring and not only as a tool for exploration, it should

Table 1

Classification of alarms according to the existing standards

Type of alarm	Alarm category	Note	Standard
Electric or pneumatic failure	High priority		EN 794–1 [12]
FI_{O2} high or low	At least medium priority	Is applicable as soon as O_2 concentration is different from that of ambient air	EN 794–1
Paw high	High priority		EN 794–1
VE low* or VT low*	At least medium priority		EN 794–1
Apnoea	At least medium priority		EN 794–1
Disconnection	At least medium priority	Could be detected for example from a low Paw, a low ET_{CO2} and a low tidal volume	EN 794–1
Continuous pressure	High priority	Is relative to a continuous pressure kept over a given limit during more than 15 ± 1.5 s	EN 794–1
ET_{CO2}			
High	Medium priority		EN 864 [14]
Low	Medium priority		EN 864
FI_{CO2} high	Medium priority		EN 864
Sp_{O2}			
High	No priority indicated	For neonatology	EN 865 [15]
Low	No priority indicated		EN 865
Sensor failure	Low or medium priority		EN 865

*According to these standards, except for the ventilators used in neonatology, the measurement of expiratory tidal volume (VT) or minute ventilation (VE) must be provided. Only the parameters and events listed in the standards are reported here. The values of high and low alarm limits are set by the medical staff. An alarm of high priority implies an immediate response from the staff; an alarm of medium priority implies a prompt response from the staff; an alarm of low priority is used to attract staff's attention. ET_{CO2}, end tidal CO_2; FI_{CO2}, concentration of carbon dioxide during inspiration; FI_{O2}, concentration of dioxygen during inspiration; Paw, airway pressure; Sp_{O2}, saturation of oxyhemoglobin determined by pulse oximetry.

provide alarms of medium priority for high and low end tidal CO_2 values and a high concentration of carbon dioxide during inspiration.

The standard related to pulse oximetry [15] specifies that when an oximeter is used for monitoring purposes, it should provide an alarm for a low saturation of oxyhemoglobin determined by pulse oximetry (Sp_{O2}). If a default value is provided, it should be more than 80%. When used in neonatology, an alarm for a high Sp_{O2} should be a supplementary factor of safety.

These standards provide the following: on one side, a classification of the alarms according to a level of emergency (high, medium and low) with audible characteristics corresponding to each of these levels, and on the other side, for each monitoring system, the events or parameters that should provide an audible alarm with a given degree of emergency (Table 1).

Very few monitoring systems currently use these standards, and to our knowledge there are no data to say whether or not such an implementation would improve alarm management.

Because the number of false alarms increases as the number of monitors increases [16], one method should be to optimize the level of monitoring. This is approached through some recommendations edited by the American Association of Respiratory Care (AARC) on the use of some monitoring systems such as capnography [17] and pulse oximetry [18] (see also http://www.hsc.missouri.edu/~shrp/rtwww/rcweb/aarc/). These recommendations, based on a review of the current literature, provide for each monitor information such as indications, contraindications and assessment of need. More recently, the Société de Réanimation de Langue Française (SRLF) published recommendations for the monitoring of ventilated patients according to pathology, mode of ventilation and age [19].

Technical and research studies

Many studies have shown that the number of false alarms on the Sp_{O2} signal is particularly important because of bad connections and poor contact [2–4]. They are more often due to motion artifact. In the current clinical context, switching off the redundant alarms is a solution that can be considered if the patient's safety is assured. For example, in the paediatric context, except for severe respiratory distress syndrome, an alarm on high and low values for Sp_{O2} and on the transcutaneous partial pressure of O_2 (Ptc_{O2}) is not justified, even if these alarm settings are otherwise justified for the preterm infant. It is therefore possible to choose to switch on an alarm on a low Sp_{O2} and a high Ptc_{O2} and to switch off the alarm on a high Sp_{O2} and

a low Ptc_{O2} [20]. Technical solutions have been proposed by some manufacturers. A new technology approach, termed Masimo Signal Extraction Technology (Masimo, Irvine, California, USA; see http://www.masimo.com/clinical.htm), was introduced recently; when tested on healthy volunteers during standardized motion procedures, this technology showed lower error rates than those of other oximeters [21]; a clinical study conducted in a paediatric critical care unit confirmed these results [22].

Some research studies have been conducted to decrease the number of false alarms. In a study by Rheineck-Leyssius and Kalkman [23] performed off-line on data for 200 post-operative patients, the authors compared the effect of different methods on the number of true and false alarms: alarm delay (2–44 s) with an alarm limit set to 90%, a mean and median filter (10–90 s) and decreasing the alarm limit from 90% to 85%. Results showed that in this specific context, it might be preferable to use a longer filtering epoch rather than to decrease the lower alarm limit. The use of median filtering techniques seems an interesting solution to the problem of decreasing the number of false alarms for data coming from the ventilator [24] as well as those coming from the cardiovascular monitor [25]. In this last study, the results showed that the frequency of false alarms was reduced by more than two-thirds compared with a typical patient monitor.

As well as these monoparametric approaches, a multiparametric approach such as data fusion has been explored: it is a method designed to compute data from multiple sensors and to use the redundancy to improve the quality of the information produced in terms of the quality of the monitored data and alarm management. This approach is particularly suitable for heart rate, which can be obtained from different sources (every derivation of the electrocardiogram signal, Sp_{O2} and arterial pressure) [26].

Most of the studies are seeking to reduce the number of false alarms (those with no clinical significance) by using multiparametric approaches: most of the time it is the simultaneous variation of several parameters that is characteristic of an event. Probably the use of limits is useful to ensure the physiological range of a parameter but, except in specific cases that are more frequent in neonates (the detection of hyperoxy), the control of limit violation for a parameter is not what the physician is looking for. He is looking for events (such as airway obstruction, true haemoglobin desaturation and hypovolaemia). The knowledge of experts in the field is then used to determine episodes of artifact or specific events. Many studies have been conducted in this way [27–31]. More often, the medical knowledge is expressed in terms of an increase, a decrease, the stability or the instability of a parameter. In this approach, it is the trend or the pattern of the parameter more than its current value that is taken into account. The results seem promising, but on-line clinical validation is needed to compare the performance of such systems with current monitoring in detecting false alarms. On-line documentation of the events and the development of multiparametric procedures on the available data are other perspectives that are being explored. Rather than using expert knowledge first, we are trying to extract the relationships directly from the data [32] and to compare our findings with what has happened in the clinical context.

Conclusion

The review of the current literature permits the conclusion that the present monitoring is safe but the mode of alarm generation is the source of many false alarms if we consider a false alarm as an alarm with no clinical relevance.

Currently there is no obvious solution, but some improvement could be made by following two main objectives: the adaptation of the choice of the element of monitoring to each patient, and the development of technical solutions with multiparametric approaches to detect events that are clinically relevant.

Acknowledgements

I thank Professor Claude Chopin for stimulating discussions on the role of monitoring: I am just an observer; he is a practitioner. I also thank Janette Andre, who corrected the English manuscript.

References

1. Pierson DJ: **Goals and indications for monitoring.** In *Principle and Practice of Intensive Care Monitoring*. Edited by Tobin MJ. New York: McGraw-Hill, Inc; 1998:33–44.
2. Lawless ST: **Crying wolf: false alarms in a pediatric intensive care unit.** *Crit Care Med* 1994, **22**:981–985.
3. Tsien CL, Fackler JC: **Poor prognosis for existing monitors in the intensive care unit.** *Crit Care Med* 1997, **25**:614–619.
4. Chambrin MC, Ravaux P, Calvelo D, Jaborska A, Chopin C, Boniface B: **Multicentric study of monitoring alarms in the adult intensive care unit (ICU): a descriptive analysis.** *Intensive Care Med* 1999, **25**:1360–1366.
5. Meyer TJ, Eveloff SE, Bauer MS, Schwartz WA, Hill NS, Millman RP: **Adverse environmental conditions in the respiratory and medical ICU settings.** *Chest* 1994, **105**:1211–1216.
6. Balogh D, Kittinger E, Benzer A, Hackl JM: **Noise in the ICU.** *Intensive Care Med* 1993, **19**:343–346.
7. Aaron JN, Carlisle CC, Carskadon MA, Meyer TJ, Hill NS, Millman RP: **Environmental noise as a cause of sleep disruption in an intermediate respiratory care unit.** *Sleep* 1996, **19**:707–710.
8. Kam PCA, Kam AC, Thompson JF: **Noise pollution in the anaesthetic and intensive care environment.** *Anaesthesia* 1994, **49**: 982–986.
9. Cropp AJ, Woods LA, Raney D, Bredle DL: **Name that tone: the proliferation of alarms in the intensive care unit.** *Chest* 1994, **105**:1217–1220.
10. Koski EM, Maakivirta A, Sukuvaara T, Kari A: **Clinician's opinions on alarm limits and urgency of therapeutic responses.** *Int J Clin Monit Comput* 1995, **12**: 85–88.
11. Comité Européen de Normalisation. European Standard. Medical devices. Electrically generated alarm signals. EN 475:1995.
12. Comité Européen de Normalisation. European Standard. Lung ventilators. Part 1: Particular requirements for critical care ventilators. EN 794-1:1997.
13. Sanborn WG: **Microprocessor-based mechanical ventilation.** *Respir Care* 1993, **38**:72–109.
14. Comité Européen de Normalisation. European Standard. Medical electrical equipment. Capnometers for use with humans. Particular requirements. EN 864:1996.

15. Comité Européen de Normalisation. European Standard. Pulse oximeters. Particular requirements. EN 865:1997.
16. Kacmarek R: **Alarms.** In *Principle and Practice of Intensive Care Monitoring*. Edited by Tobin MJ. New York: McGraw-Hill, Inc; 1998:133–139.
17. AARC Clinical Practice Guideline: **Capnography/capnometry during mechanical ventilation.** *Respir Care* 1995, **40**: 1321–1324.
18. AARC Clinical Practice Guideline: **Pulse oximetry.** *Respir Care* 1991, **36**:1406–1409.
19. Recommandations d'experts de la SRLF: **Le monitorage et les alarmes ventilatoires des malades ventilés artificiellement.** *Réanim Urgences* 2000, **9**:407–412.
20. Chambrin MC, Storme L, Lemoine D, Usselio A: **Les alarmes des paramètres monitorés: principes généraux et gestion.** *Réanim Urgences* 2000, **9**:432–438.
21. Barker SJ, Shah NK: **Effects of motion on the performance of pulse oximeters in volunteers.** *Anesthesiology* 1996, **85**: 774–781.
22. Bohnhorst B, Peter CS, Poets CF: **Pulse oximeters' reliability in detecting hypoxemia and bradycardia: comparison between a conventional and two new generation oximeters.** *Crit Care Med* 2000, **28**:1565–1568.
23. Rheineck-Leyssius AT, Kalkman CJ: **Influence of pulse oximeter settings on the frequency of alarms and detection of hypoxemia: theoretical effects of artifact rejection, alarm delay, averaging, median filtering or a lower setting of the alarm limit.** *J Clin Monit Comput* 1998, **14**: 151–156.
24. Young WH, Gardner RM, East TD, Turner K: **Computerized ventilator data selection: artifact rejection and data reduction.** *Int J Clin Monit Comput* 1997, **14**:3, 165–176.
25. Mäkivirta A, Koski E, Kari A, Sukuvaara T: **The median filter as a preprocessor for a patient monitor limit alarm system in intensive care.** *Comput Methods Programs Biomed* 1991, **34**: 139–144
26. Feldman JM, Ebrahim MH, Bar Kana I: **Robust sensor fusion improves heart rate estimation: clinical evaluation.** *J Clin Monit* 1997, **13**:379–384.
27. Koski EM, Sukuvaara T, Mäkivirta A, Kari A: **A knowledge-based alarm system for monitoring cardiac operated patients: assessment of clinical performance.** *Int J Clin Monit Comput* 1994, **11**:79–83.
28. Schoenberg R, Sands DZ, Safran C: **ICU alarms meaningful: a comparison of traditional vs trend-based algorithms.** *Proc AMIA Symp* 1999, 379–383.
29. Cao C, McIntosh N, Kohane I, Wang K: **Artifact detection in the PO2 and PCO2 time series monitoring data from preterm infants.** *J Clin Monit Comput* 1999, **15**:369–378.
30. Hunter J, McIntosh N: **Knowledge-based event detection in complex time series data.** In *Lecture Notes in Artificial Intelligence 1620*. Edited by Horn W, Shahar, Lindberg, Andreasson, Wyatt. Berlin: Springer-Verlag; 1999:271–280.
31. Haimowitz IJ, Kohane IS: **Managing temporal trend diagnosis.** *Artif Intell Med* 1998, **8**:299–321.
32. Calvelo D, Chambrin MC, Pomorski D, Ravaux P: **Towards symbolization using data-driven extraction of local trends for ICU monitoring.** *Artif Intell Med* 2000, **19**:203–223.