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Frequency and reliability of alarms in the monitoring of cardiac postoperative patients

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Abstract

Postoperative monitoring of cardiac operated patients requires appropriately functioning monitor alarms as well as intensive nursing activity. The limit alarms can be used for detection of life-threatening situations and monitoring of physiological changes in the patient's state. We studied the significance and the frequency of audible alarms during the postoperative intensive care of ten cardiac patients. Of 1307 occasions when such an alarm was activated during the study period of approximately 26 hours per patient, only 139 (10.6%) were significant. The highest proportion of significant audible limit alarms was found during the immediate postoperative period. Heart rate alarms were more reliable than alarms of the other parameters monitored in the study. Possibilities for improving the physiological monitoring and alarm system are discussed.

Introduction

The limit alarms of the present monitors are commonly used both for the detection of vital organ failures and for monitoring of a patient's physiological state. Both applications are susceptible to unnecessary alarms. These alarm systems produce a great number of alarms caused by measurement artifacts, movements of the patient or by minor problems such as transient fluctuations past the set alarm limits [1]. Poor reliability of alarms decreases their acceptance and thus increases the resistance to their use. This may, however, lead to critical or even life-threatening situations [2].

The malfunctioning of monitors or other vital instruments may lead to serious complications or failures in the therapy. In one report 3% of admissions to an intensive care unit suffered adverse incidents. Often human error was reported to be the cause of this type of an incident. The mortality of patients in the adverse incident group was statistically significantly higher than that among the rest of the patients [3].

This study was performed to determine both the frequency and the significance of audible limit alarms during the postoperative haemodynamic monitoring of cardiac patients.

Patients and methods

The study consisted of a monitoring period starting from the admission of the patient to the ICU and ending at the first postoperative day, six hours after the removal of chest drains. Of the ten adult patients studied, nine underwent a coronary by-pass operation and one had a cardiac valve replacement.

The alarms for the following haemodynamic parameters were studied: the heart rate (HR), the systolic (SAPs), mean (SAPm) and diastolic (SAPd) systemic arterial pressures, the systolic (PAPs), mean (PAPm) and diastolic (PAPd) pulmonary arterial pressures, and the mean central venous pressure (CVPm). These parameters were measured using a standard multichannel patient monitor (Kone 565, Kone Monitoring Systems, Instrumentarium Co, Helsinki, Finland). The monitors process the HR values every other second by averaging the frequency of the beats within the last five seconds. The heart rate was determined from the arterial pressure curve. The displayed pressure values in the monitors were calculated by averaging the values within the last nine seconds.

For the detection of systemic arterial pressure (SAP), pulmonary arterial pressure (PAP), and mean central venous pressure (CVPm), we used Gould® P50-pressure transducers and Spectramed® pressure measuring sets with continuous flow of 3 ml/h and manual flushing capability. The visible limit alarms of the monitors were activated instantly as the detected average value surpassed the set limit and the audible alarms after a delay of five seconds. Only the audible alarms were applied in the study.

The limit alarms for the HR and all SAP values were set at ± 20% from the optimal values, which were determined using routine clinical considerations. For each specific case the alarm limits for CVPm and all PAP values were set as clinically indicated. If the clinicians changed the optimal values during the study, the alarm limits were redetermined accordingly.

Nurses experienced in the postoperative care of cardiac patients recorded the time and parameters of every alarm activated during the study period. Each nurse used his or her clinical judgement to consider the necessity of action to the alarm. After taking an action, he/she recorded the significance of the alarm using the following classification:

1. Artifact alarm
   * A technical artifact alarm; disconnection or occlusion of pressure line, drawing of blood sample, detachment of ECG electrode etc.
   * An unimportant alarm of short duration – a limit alarm not exceeding 15 seconds.
2. Undue alarm – no action taken
   Limit alarm surpassed for a period longer than 15 seconds but the nurse took no other action except a brief checking of monitoring system and silencing of the alarm.
3. Significant alarm – patient condition checked
   Due to the activation of the alarm, the nurse considered necessary to examine the patient's condition.
4. Significant alarm – treatment implemented
   Alarm resulted in a therapeutic action.

This study was devided into five subperiods:

1. Rewarming period – from the admission to ICU until the peripheral temperature reached 30° C.
2. Recovery period – from the end of the rewarming period until weaning from the ventilator was initiated.
3. Weaning period – from the start of weaning until extubation of the endotracheal tube.
4. Rehabilitation period – from extubation until the removal of chest drains.
5. Follow-up period – a period of six hours after the end of the rehabilitation period.

The mean durations of monitoring periods are shown in Table 1.

Results

This study consisted of a total of 400 hours approximating 26 hours per patient (Table 1). The total number of individual parameter alarms was 2322 and the number of alarm events, occasions when the alarms were activated by one or more parameters, was 1307. The number of alarm events was lower because many of these contained multiple parameter alarms – e.g. during the measurements of pulmonary capillary wedge pressure all alarms for the PAP parameters were activated.

The total number of alarms recorded per period was high during the rewarming, recovery and rehabilitation periods (Table 1). A lower number was found during the weaning period, and the lowest during the follow-up period.

The distribution of the alarms according to their clinical significance is shown in Fig. 1. The alarms classified into categories 1 and 2 were considered to be non-significant, and the rest significant. Only 139 (10.6%) of 1307 alarm events were significant. The proportion of significant alarms was highest during the rewarming period. Thereafter, the number of significant alarms diminished (Table 2).

The periodical significance of the parameterized alarms are shown in Table 2. The greatest clinical significance was noted on SAP and PAP alarms during the rewarming period. The SAP alarms maintained some significance during the recovery and weaning periods. Of the monitored parameters, HR alarms were noted to have the highest significance.

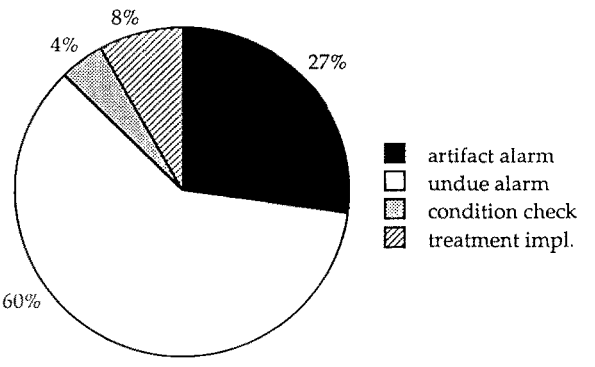

Fig. 1. The clinical significance of recorded alarms. A minority (12%) of alarms caused a significant medical action.

Discussion

We studied the reliability and frequency of alarms, which were activated during the postoperative haemodynamic monitoring of cardiac patients.

Both the total number of alarms and the number of alarm events were high. The proportion of significant alarms was low, and the majority of these appeared during the first three periods. Therefore, only a minority of the limit alarms seemed to inform us of emergencies or physiological alterations requiring therapy.

The periodic variation in alarm frequency was probably caused by several of the following factors.

Table 1. Durations of monitoring periods and their corresponding alarm numbers during postoperative care monitoring of ten cardiac operated patients.

	Duration (mean ± S.D.) (h)	Number of alarms
1. Rewarming period	4.23 ± 1.63	425
2. Recovery phase	2.87 ± 1.81	244
3. Weaning period	6.66 ± 3.80	524
4. Rehabilitation period	12.47 ± 7.23	803
5. Follow-up period	6.00 ± 0.00	326
Total	26.2 ± 2.8	2322

During rewarming, the physiological state of the as yet anesthetized patient was rather stable and only varied in response to anxiety at moments of abrupt emergence. The cardiac output was low and redistrubition of circulation required continuous adjustment of therapy. Also during the rewarming period most alarms seemed to be either true signals requiring therapy or artifactual ones caused by frequent manipulations of pressure lines. Thereafter, the increase in nursing activity probably caused most of the fluctuations in the monitored values.

If we combine the study periods, the most reliable alarms came from the HR parameter. After the rewarming period, HR appeared to stabilize and any changes in this parameter were likely to denote significant alterations in the patients' physiological state.

The reliability of SAP alarms decreased as the patients' recovery progressed. Until extubation, there seemed to be a tendency toward low SAP values as the cardiac output was still insufficient. Later, the sampling of arterial blood and physiological alterations of short duration caused numerous nonsignificant alarms.

All PAP alarms were rather reliable during the rewarming period, but later – as the patient regained conciousness – their specificity decreased considerably. This may be the result of alarms activated by the measurements of pulmonary capillary wedge pressure, as well as due to spontaneous

coughing, airway suctioning or physiotherapy of the conscious patient.

The CVPm alarms were rather significant during the rewarming period when they signalled the need to alter the infusion therapy. The use of the CVP line in the measurement of cardiac output caused most of the false alarms in this parameter. Later the specificity of these alarms diminished markedly due to interference similar to that affecting the PAP parameters.

Awakening of the patient generally affected all parameters and commonly activated one or more alarms. The number of alarms recorded during the study may have been affected by the inactivation period of the alarms. In the Kone 565 monitor this period lasts 255 seconds after the silencing of the alarm system.

As a consequence of the continuously worsening shortage of ICU personnel, the nurses have to divide their attention between a varying number of patients. To compensate for the periodic lack in vigilant observation, the alarm systems must be used actively. The monitors' alarm systems are aimed to assist nurses and doctors to monitor the patient's physiological stability and to adjust therapy if necessary. However, the wide physiological variability in the registered parameters greatly hinders the use of limit alarms to notify of unphysiological changes and leads to unsatisfactory working conditions as attention must be paid to the repeatedly occurring alarms.

The greatest advantage of using limit alarms is their ability to detect abrupt life-threatening situations. The frequency of alarms indicating such situations is very low, which may tempt the users to silence the alarms [4]. Setting the range of limit alarms sufficiently wide enough to avoid insignificant alarms could still permit the prompt activation of the alarm in emergency situations. This could, however, lead to a failure to detect a slow worsening in the patient's state [5], and the implementation of therapeutic actions may also be delayed until the monitored values are well outside the optimal range.

Our results suggest that our present limit alarm system is oversensitive to false alarms from various sources and requires considerable efforts for improvement. The present monitors commonly utilize averaging filters which diminish sudden spikes in the signals. If the magnitude of artefactual deviation is very high, the averaging filter cannot filter it completely. The median filtering methods, however, are capable of removing variations lasting less than half the number of samples (parameter values) used for its calculation, regardless of their magnitude [6]. Therefore, they are more accurate both in retaining the actual variability and in removing artefactual signals in the trend. Also, improved methods could be used for detecting cut-offs due both to the sampling of blood as well as measurements of pulmonary capillary wedge pressure and cardiac output.

Table 2. Distribution of alarms according to their significance and to the periods. (Mean number of alarms ± S.D. per monitored hour per patient).

Period	HR	SAPs	SAPm	SAPd	PAPs	PAPm	PAPd	CVPm
1. S	0.07 ± 0.20	0.45 ± 0.39	0.43 ± 0.40	0.68 ± 0.70	0.41 ± 0.56	0.32 ± 0.56	0.28 ± 0.54	0.17 ± 0.21
NS	0.32 ± 0.65	1.13 ± 0.70	1.46 ± 0.98	1.82 ± 1.16	0.81 ± 0.82	0.47 ± 0.53	0.50 ± 0.53	0.56 ± 0.47
2. S	0.12 ± 0.15	0.31 ± 0.36	0.32 ± 0.37	0.50 ± 0.94	0.18 ± 0.37	0.03 ± 0.10	0.09 ± 0.19	0.09 ± 0.19
NS	0.22 ± 0.36	1.34 ± 1.55	2.14 ± 2.76	2.01 ± 20.54	0.53 ± 0.82	0.48 ± 0.79	0.50 ± 0.78	0.38 ± 0.53
3. S	0.20 ± 0.39	0.28 ± 0.42	0.23 ± 0.34	0.25 ± 0.37	0.03 ± 0.09	0.01 ± 0.04	0.03 ± 0.09	0.02 ± 0.06
NS	0.33 ± 0.80	1.10 ± 1.13	1.18 ± 0.76	1.31 ± 1.30	0.92 ± 1.14	0.58 ± 0.69	0.47 ± 0.56	0.48 ± 0.45
4. S	0.01 ± 0.02	0.16 ± 0.27	0.14 ± 0.27	0.23 ± 0.53	0.06 ± 0.14	0.06 ± 0.08	0.06 ± 0.08	0.06 ± 0.08
NS	0.20 ± 0.19	1.35 ± 2.27	1.79 ± 2.24	1.57 ± 2.27	0.98 ± 0.96	1.07 ± 1.54	1.12 ± 1.50	0.95 ± 1.10
5. S	0	0.07 ± 0.17	0.04 ± 0.11	0.06 ± 0.08	0	0.02 ± 0.07	0.02 ± 0.06	0.04 ± 0.07
NS	0.17 ± 0.25	0.67 ± 0.56	1.17 ± 1.10	0.91 ± 0.82	1.19 ± 2.32	0.56 ± 0.77	0.67 ± 0.87	0.48 ± 0.47

S = significant alarm; NS = non-significant alarm.

Multiple parameter detection is another alternative to avoid undue alarms [7]. Loss of the ECG signal should not lead to activation of the asystole alarm on condition that either SAP or PAP parameters retain their proper pulse form. Expert systems built into the monitors could increase the reliability of the alarms processing combinations of parameter values. They could warn us of states like hypovolaemia or hypoventilation instead of simply indicating the status of individual parameters.

Conclusions

During our study the postoperative haemodynamic monitoring of cardiac patients produced numerous alarms, of which only one tenth were clinically significant. The limit alarms were mostly triggered without a need for therapeutic action, which decreased the usefulness of limit alarms to warn the personnel of critical changes in the patient's state. The alarms caused by clinically insignificant changes of short duration can most probably be eliminated with filtering techniques. Another possibility is to increase the intelligence of monitoring alarms. The use of combinations of parameters or even expert systems may solve the problem of false alarms in the future.

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