MANAGING THE MONITORS: AN ANALYSIS OF ALARM SILENCING ACTIVITIES DURING AN ANESTHETIC PROCEDURE

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Patient monitoring devices are designed to assist users in obtaining information on the patient and life-support equipment status. Most of the these devices have built-in visual and auditory alarms, which are to help the user to manage attention allocation. In this presentation we describe an analysis of the interaction between care providers and the monitoring devices during an anesthetic procedure (airway management) for trauma patients in the real environment. The videotapes of 47 cases were analyzed by coding the activities in silencing auditory alarms. In majority of the cases (87%) alarms could be heard yet only a small portion of the cases (6%) contained patient status events that signified by the alarm conditions. Care providers were frequently forced to interrupt clinical tasks to silence alarms. The differences in silencing frequency and rapidity among different monitoring devices suggest that alarms could be designed to be less intrusive and more tolerable, thus making the monitors easier to manage in critical care settings

The view of many people is that the best patient monitoring device in the operating room is the vigilant anesthesiologist. However, this rationale assumes that: physiological monitoring of patient function replaces vigilance by the care providers. In reality, physiological monitors should augment the anesthesiologist's vigilance. Among the means used to increase vigilance and warning of impending or current events are the use of auditory alarms and visual displays.

This view of the anesthesiologist-as-monitor also assumes that it is unusual for anesthesiologists to have lapses in concentration. In reality, fatigue and distractions, including high or low workload, may result in a lack of concentration on the patient and patient monitors, resulting in a failure to detect an event detrimental to patient safety. The question is are visual and auditory alarms a help or a hindrance to patient safety?

Within the past 25 years the status of patient monitoring has changed from observation and physical examination into a profusion of different monitoring devices and alarms systems that warn of acute or slowly changing events. In addition to an increased complexity and duration of surgical procedures, patient monitoring devices have proliferated. New patient monitoring devices are introduced into the operating room environment with high frequency. This results in a lack of integration among monitoring systems, and a failure of harmonization of alarms. The status of patient alarms systems in the operating room as we enter the 21st Century is itself alarming because they are confusing, contradictory, non-intuitive, in many cases proprietary and without standardization (Topf & Dillon, 1988; Hedley-Whyte, Godinez, & Weitzner, 1994; Grumet, 1993; Stafford, 1982; Cropp, et al, 1994; Meredith & Edworthy, 1995). Many alarms have a high false positive, and low validity and unimportance in relation to the patient event (Kestin, Miller, & Lockhard, 1988; Lawless, 1994; Block & Schaaf, 1996; Kerr, 1985; Bliss, Gilson, & Deaton, 1995). Because monitors can provide incorrect or unnecessary information, so can alarms distract the anesthesiologist or suggest abnormalities that are false or unimportant in relation to other simultaneously occurring events. The present concept of alarms in the operating room suffers from an over-simplification and a lack of clear understanding by designers of how distracting auditory and visual alarms can be, and what information the alarms are intended to convey.

METHODS

There are few published reports on the intrusiveness of auditory alarms. The objective of this study was to quantify the intrusiveness of auditory alarms in real clinical settings. We analyzed videotapes of real-life patient care and extracted data on (1) timing of auditory alarms, (2) occurrences of superfluous alarms, and (3) care providers' efforts to silence auditory alarms. The analysis was focused on auditory alarms during airway management (tracheal intubation), a high-workload period during which numerous auditory alarms occur.

Through a system described elsewhere(Mackenzie, Hu, & Horst, 1995) , audio-video tapes were acquired during real patient resuscitation and anesthesia in two patient admitting areas and two operating rooms in a university affiliated Level-

I trauma center. The acquisition of videotapes was a part of a study which was approved by the Institutional Review Board. Blood pressure (arterial and non-invasive), pulse oximetry, end-tidal CO_2, heart rate, and temperature readings were obtained from patient monitors and overlaid on the video images for later review.

Auditory alarms from three monitoring devices were analyzed: mechanical ventilator (Siemens Servo 900C), blood pressure/heart rate (BP/HR) monitor (Mennen Horizon 2000), end-tidal CO_2/pulse oximetry (ETCO2/SPO2) monitor (Nellcor 200). The identical three devices were used in all studied cases.

All videotapes that captured airway management were included for the current study. Data on alarm activities were extracted for the period between mask pre-oxygenation before tracheal intubation and successful mechanical ventilation through an endo-tracheal tube. The timing of auditory alarms and silencing activities was obtained by reviewing videotapes played on computer-driven video cassette recorders. The ending time of intermittent alarms (used by the ETCO2/SPO2 monitor) was determined by a cessation of longer than three seconds.

One of two codings was assigned to each alarm: superfluous and significant. Superfluous alarms were coded as follows: (1) ventilator alarms occurring during airway suctioning, direct laryngoscopy, or when the mechanical ventilator was turned on but not connected to the patient; (2) ETCO2/SPO2 monitor alarms occurring when systolic blood pressures were unrecordable (below 60 mmHg), or the finger probe was not properly placed due to patient movement, or when the probe was not connected; (3) the BP/HR monitor alarms occurring when the values were unchanged, or within normal range (systolic between 100 to 160 mm Hg), or obtained during cardiopulmonary resuscitation. When a care provider pressed the silence button to end an auditory alarm, that alarm was coded as a silenced alarm.

Four measures were used to quantitate the intrusiveness of alarms: (1) *Alarm on-off ratio*: the proportion of the time during airway management in which auditory alarms sounded, (2) *Superfluous alarm rate*, (3) *Alarm silencing frequency*: the proportion of alarms which were silenced (the rest of the alarms ended when problems causing the alarm were corrected), and (4) Rapidity of *alarm silencing*: the duration of an alarm before silencing.

The occurrences of alarms were compared between elective (in the operating rooms) and emergency (in the patient admitting areas) airway management cases and three monitoring devices. Unless specified otherwise, one tailed t-tests were used for comparison of means, with $p < 0.05$ as being significant.

RESULTS

Forty-seven videotaped cases contained airway management and they were collected during a period of three years. Twenty-eight of which were emergency cases in the patient admitting areas and 19 elective cases in the operating rooms. The mean duration of airway management (from mask oxygenation to successful mechanical ventilation) was 531 seconds. Airway management duration did not vary significantly between elective cases and emergency cases.

In 46 out of 47 cases auditory alarms occurred from one or more of the three studied devices during airway management (Figure 1). Ventilator alarms sounded in 87% (41/47) of the cases, more frequently (χ^2 test, $p<0.05$) than ETCO2/SPO2 alarms (63.8%, 30/47) or BP/HR alarms (68%, 32/47). The alarm on-off ratio was 33%±4%. During emergency airway management the alarm on-off ratio (41±6%) was higher ($p<0.01$) than that during elective airway management (22±3%).

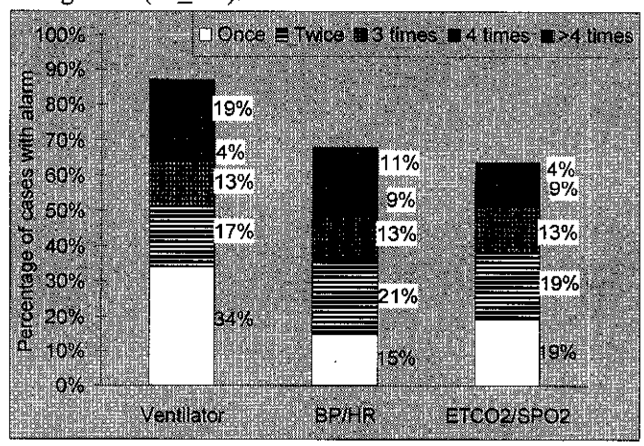

Figure 1: Percentage of cases that had 1, 2, 3, 4, and >4 alarm occurrences during the airway management.

The three monitoring devices often sounded alarms multiple times during airway management, particularly the ventilator (Table 1). On the average, the ventilator auditory alarm occurred 2.7 times each case, significantly more frequently than BP/HR and ETCO2/SPO2 monitor alarms. During elective airway management, ventilator alarms occurred more frequently compared to the other two monitoring devices.

The majority of all alarms from the three monitoring devices were superfluous: 85% of the ventilator alarms, 56% of the BP/HR monitor alarms, and 72% of the ETCO2/SPO2 alarms were superfluous; the differences in superfluous alarm rates among the three devices were not significant.

Table 1. Number of alarm soundings during each airway management. BP/HR: blood pressure and heart rate monitor; ETCO2/SPO2: end-tidal CO2/pulse oximetry monitor. *: $p<0.01$ comparing ventilator alarms with BP/HR monitor alarms; **: $p<0.01$ comparing OR cases with AA cases as well ventilator alarms with BP/HR monitor alarm within OR cases.

Mean±SEM	Ventilator	BP/HR	ETCO2/ SPO2
All cases	2.7±0.39*	1.5±0.22	2.1±0.33
OR	4.8±0.68**	1.6±0.40	2.0±0.60
AA	1.2±0.18	1.5±0.26	2.1±0.38
Semi-emergency	1.3±0.31	1.5±0.34	2.8±0.52
Emergency	1.1±0.21	1.4±0.39	1.6±0.51

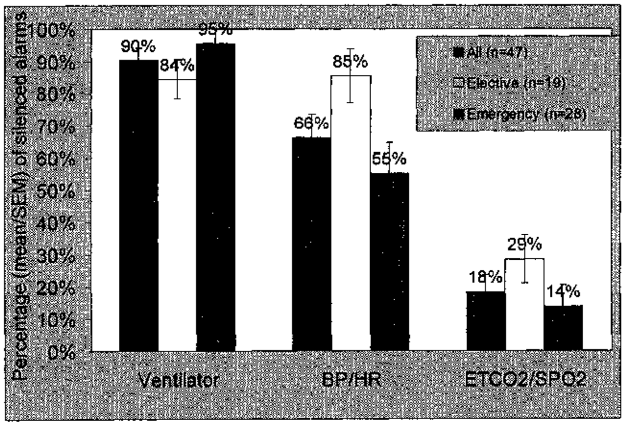

Figure 2. Alarm silencing rates. BP/HR: blood pressure/ heart rate monitor; ETCO2/SPO2: end-tidal CO_2/pulse oximetry monitor. Following comparisons were significant ($p<0.05$): (1) BP/HR alarms in emergency airway management were silenced less frequently than were those during elective airway management; (2) During emergency airway management, ventilator alarms were silenced more frequently than the BP/HR monitor alarms, which were silenced more frequently than the ETCO2/SPO2 monitor alarms.

Care providers silenced a large portion of the alarms rather than waiting for the alarms to end when problems causing the alarm were corrected (Figure 2). The silencing frequency of the ventilator alarm was 90%, significantly higher than that of the BP/HR monitor alarm (66%) and was more than 4 times of the silencing rate of the ETCO2/SPO2 alarm (18%). BP/HR and ETCO2/SPO2 alarms were silenced more frequently ($p<0.01$) during elective airway management than during emergency airway management.

The ventilator alarms were silenced within 7.4±0.8 sec of onset (Figure 3), significantly faster than those for the blood-pressure/heart-rate monitor alarms (34.6±6.2 sec) and end-tidal CO_2/Pulse oximetry monitors (55.6±16.0 sec). The ventilator alarms were silenced faster during elective airway management (5.3±0.7 sec) than were during emergency airway management (12.3±2.0 sec).

DISCUSSION

The problems with provision of an auditory alarm when a signal exceeds certain pre-defined limits include a lack of specificity (there could be numerous causes of the out-of-range signal), sensitivity (signal may be damped due to patient or equipment causes), and an excessive frequency of occurrence (especially if the limits of an alarm system are set tightly). Modern anesthesia workstations and patient monitoring systems can comprise more than 30 alarms and 70 display indicators, making alarm and display "pollution" currently a hazard in the operating room.

What should be done about this? There are several intuitive steps that would improve the present status of operating room alarm systems: 1) integration of alarm signals and systems; 2) conformity of auditory alarm displays; and 3) improved displays for visual alarms.

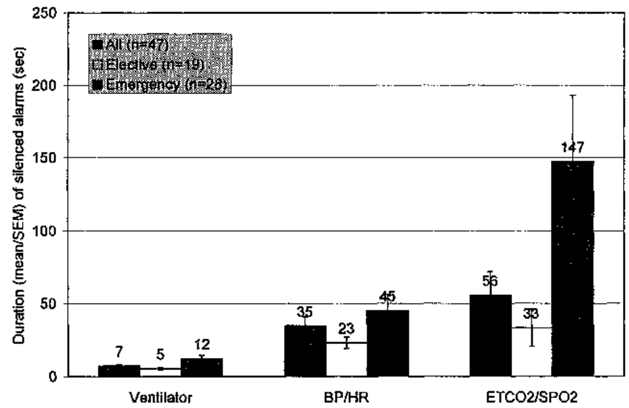

Figure 3. Rapidity of alarm silencing (sec). BP/HR: blood pressure/heart rate monitor; ETCO2/SPO2: end-tidal CO2/pulse oximetry monitor. Following comparisons are significant ($p<0.05$): (1) ventilator alarms were silenced faster than BP/HR and ETCO2/SPO2 monitor alarms, (2) Ventilator and BP/HR alarms were silenced faster during elective than during emergency airway management.

1) Integration of alarm signals and systems.

Currently, when a new piece of medical equipment is brought into the operating room and the auditory alarm sounds, the staff are confused because its tone and loudness are different. The alarm may be loud to draw attention to that particular piece of equipment and distinguish it from other auditory alarms even though relative importance of the loud equipment compared to other life support systems may be considerably less. One possible solution is to network the alarm systems so that each alarm is integrated with others. Duplicate measurements of the same signal (e.g., heart rate) could be filtered out to provide one single, theoretically more reliable, signal. The network would enable a new monitor alarm to be included, and its display harmonized with existing signals. This may minimize confusion with existing alarms and allow the new monitor signal to be prioritized relative to those already in use.

2) Conformity of auditory alarm display.

At present attempts are underway to standardize the auditory alarms by priority (or urgency), and by tone and frequency of sounding, pairing, triplets, etc. [[[xxxx references here]]] The gold standard of auditory alarms is the pulse oximeter. This auditory signal "display" provides 4 pieces of information to the anesthesiologist. The heart rate, the value of arterial O_2 saturation, change in heart rate, and a quantifiable change in O_2 saturation below 100%. This information is provided by linking the pulsation of blood flow during heart contraction with the instantaneous analysis of O_2 saturation.

This principle of linking related components of vital signs is applicable with other signals such as end-tidal carbon dioxide analysis, and rate and volume of respiration since the data is interdependent. As rate and depth of respiration increases, so the end-tidal carbon dioxide decreases. This linkage could be incorporated into an auditory display.

Other possible improvements in alarm displays include a one-time sound when alarm limits are reached (instead of the current continuous alarm sounding) linked to a visual display of the limit that has been exceeded. The alarm sound would be repeated again at set intervals (say one minute) while the visual display would remain constantly throughout the duration of the out-of-range variable.

3) Improved displays for visual alarms.

Present physiological monitors and anesthesia work-stations have a variety of formats for their visual displays. Operating room suites have visual displays that are important for patient care, but have variability in the usability of their human interface. As an example, volume output from an indwelling bladder catheter can be collected in three different ways with different degrees of usability: a bag with no volume calibration, a bag with crude volume calibrations or an accurate (within 5 ml) volume measurement device. Obtaining the reading from one of these monitors and thus identifying alarm states can be either easy, with the accurately calibrated volume meter, or difficult, with the lack of or crude container volume calibration. The governing principle underlying the monitor or device design should be a clear understanding of what information the monitor should be trying to display.

There is a place for intelligent on-line analysis of complex waveforms, and for pattern recognition of a constellation of signals. Electrocardiograph displays can be automatically interpreted with high degree of accuracy to provide information not only about heart rate, but rhythm variation, occurrence of artifacts, and trends in change of different parts of the waveform associated with myocardial ischemia (e.g., ST segment analysis) during an anesthetic. The combination of trends of increasing heart rate, decreasing blood pressure, end tidal CO_2, and increased heart rate variability can be used to suggest that the patient is hypo-volemic. This and other such patterns could be integrated into a visual display updated every 15 minutes or so. Such displays may be helpful to the clinician monitoring a complex case over prolonged periods of time.

Whether current alarms and displays are friend or foe depends on the interpretation of and experience of each clinician. Pulse oximetry has a friendly "auditory display," other monitors, e.g., respiration and circulation, currently lack such well designed auditory alarm systems; but we believe they could have a similar "auditory display" that links interdependent data sources for these important life support vital signs.

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