Physiologic Monitoring Alarm Load on Medical/ Surgical Floors of a Community Hospital

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ABSTRACT

It has been known to the public that high frequency of false and/or unnecessary alarms from patient monitoring devices causes "alarm fatigue" in critical care. But little is known about the impact to care on the less acute patients located outside the critical care areas, such as the traditional medical/surgical (med/surg) floor.

METHODS: As part of a larger population management study, we initiated continuous physiological monitoring to 79 beds of floor patients in a community hospital. In order to qualify the patient monitoring alarm load for subacute medical and surgical floor patients, we assessed alarm data from April 2009 to January 2010. A standard critical care monitoring system (Philips IntelliVue MP-5 and Telemetry) was installed and set to the default alarm limits. All waveform data available for the patient (typically ECG, RESP, PPG at 125hz 8 bit), all alarm conditions declared by the monitoring system, and 1 minute parameter trend data were saved to disk every 8 hours for all patients. A monitoring care protocol was created to determine whether the patient was monitored via the hardwired bedside or wirelessly via telemetry. Alarms were not announced on the care unit but instead notifications were the responsibility of remote telehealth center personnel. We retrospectively evaluated the frequency of alarms over specific physiologic thresholds (n= 4104 patients) and conducted adjudication of all alarms based on a smaller sampling (n=30 patients).

RESULTS: For all patients, the average hours of monitoring per patient were 16.5 hours with a standard deviation (s) of 8.3 hours and a median of 22 hours. The average number of alarms (all severities) per patient was 69.7 (s =90.3, median =28) alarms. When this is adjusted to the duration of monitoring, the average per patient, per day rate was 95.6 (s =124.2, median =34.2) alarms. The adjudicated sample (n=30 patients) resulted in 34% of critical alarms (lethal arrhythmias, extreme high or low heart rate [HR], extreme desaturation, apnea) being true and 63% of the high priority alarms (high or low HR, high or low RR, Low SpO_2, pause, Missed Beat, Pair PVCs, Pacer Not Pace, Non Sustain VT, Irregular HR, Multiform) being true. Analysis of alarm history resulted in the ability to reduce the HR alarm load by more than 50% with a simple limit adjustment of high HR from 120 to 130 bpm and a 36% or 65% reduction in SpO_2 alarm load by reducing the SpO_2 limit from 90% to 85% or 80% respectively.

CONCLUSION: 1) Standard critical care alarm limits appear be too sensitive for subacute care areas of the hospital. 2) For most patients these alarm limits do not create a significant alarm load; however, for a small number of patients they cause a significant alarm load. 3) Alarm loads can be controlled with alarm limit settings appropriate to the population. 4) Current technology for HR and SpO_2 appear suitable for continuous monitoring of this population.

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Clinical alarms are intended to draw attention to a significant event so that timely and appropriate action can be taken to avoid an adverse outcome. In the critical care environment, high sensitivity and specificity are designed into the alarms based on pretest likelihood of certain events and a zero clinical tolerance for false negatives. Unfortunately, this also results in frequent false and/or unnecessary alarms. In environments where the care process is either unable or unwilling to adjust limits, alarm fatigue has been shown to desensitize the care team to the alarms that are intended to protect patients.[1-6]

The term "alarm fatigue" is typically triggered by a superset of false positive alarms, and also true positives that are clinically meaningless alarms (i.e., clinicians take no clinical action). The fatigue problem stems from the high ratio of false positive and clinically meaningless true positive to clinically significant true positive alarms. Over time these alarms are ignored by clinicians who are really looking for clinically significant true positives. In care settings where the care team is close to the patient, the expected workflow to address the alarms may be obvious, but where a distributed care team with a variety of skill levels is deployed, the workflow needs to consider how alarms are distributed, and what clinical skill level is required to assess and address these alarms.

Patients cared for outside the high acuity areas of the facility clearly need physiologic data to detect and prevent patient deterioration.[7] In this application area, it is not clear what the optimal sampling of physiologic data is, or which parameters and alert levels are most important for a given patient.[7,8] As a result, many healthcare systems are deploying monitoring systems that can acquire aperiodic physiologic data on less acute patients, as well as continuously monitoring more acute patients. Introducing continuous monitoring with traditional parameter limit alarm systems to the floors with higher patient-to-caregiver ratios, lower pretest likelihood for the events the monitoring systems detect, and in some cases less skilled users can be ingredients for misadventure.

Several studies have quantified the impact in the critical care environment; however, only a few have looked at the impact to the traditional floor environment.[9] To explore the balance between the frequency of monitoring observations to detect deterioration, workflow aspects related to technical and parameter alarms, and resulting staff and patient satisfaction issues, we designed a clinical model which uses continuous physiologic data acquisition feeding a remotely located telehealth population management system and assessed alarm limits and workflow impact.

Methods

A community hospital located in urban Arizona and the entire facility's 79 med/surg beds were selected for this study. With Institutional Review Board approval, each room was instrumented with a two-way audio/video telepresence system and population management system (eICU, VISICU Philips Healthcare), a critical care bedside monitor (Intellivue MP5, Philips Healthcare) and a bidirectional WMTS telemetry system (IntelliVue Telemetry System, Philips Healthcare).

The monitors in patient rooms were configured with a custom screen and profiles (a collection of measurement, display and monitor settings) such that they normally operated as "spot check" monitors by primarily displaying tabular trend information and only used a color-coded bezel light to display the highest priority active alert. The monitors were additionally configured with a profile to support signal troubleshooting and for a more traditional real-time display of parameters, waves, and alarms in the case of patient degradation or a need to troubleshoot signal quality issues.

The floor nursing staffs were educated on the basic setup, troubleshooting, and spot check vital acquisition operation of the monitoring system. The floor staff were not educated on advance arrhythmia interpretation as these data were not displayed anywhere on the care unit, other than during troubleshooting and deterioration events. In both of these cases, representatives from the telehealth center and clinical personnel skilled in advanced arrhythmia were in attendance.

The remote telehealth center was notified of critical alarms via a "bed-to-bed overview" client and near real-time web interface from the monitoring system. A central station client (IntelliVue Information Center Central Station, Philips Healthcare) was used in the telehealth center as a control interface for patient admit,

discharge and transfer operations, optimization of alarm and algorithm settings, and to support electronic data download to the site's charting system, as well as separate proprietary alert prompts running in the telehealth center via the HL-7 physiologic data feed. While the bedside devices detected and announced parameter alarms, only the highest severity events were announced to the remote telehealth center in real time. The other lower priority alarms were not displayed to the care team but were stored in the data used for analysis.

The bedside system was configured to report only critical arrhythmias (asystole, ventricular tachycardia, ventricular fibrillation) and severe physiologic limit violations (severe desaturation, severe bradycardia, severe tachycardia, and apnea >30 seconds). Additionally the monitoring system was configured to reported significant technical alarms such as "ECG Leads Off" and "Replace Battery" messages to the remote telehealth center personnel, where they were triaged and if necessary, dispatched to the floor-based team or in some cases, the patient for rectification.

As part of a larger population management study, we initiated a baseline workflow of continuous physiological monitoring for all patients on the 79 beds. The choice of device was driven by the ambulatory needs of the patient; however, the care process called for continuous monitoring of at least SpO_2 (pulse oximetry) and pulse rate for all patients. All new admissions and post-operative patients required electrocardiogram (ECG), SpO_2, blood pressure, temperature and respiration monitoring. Ambulatory patients did not require the respiration parameter. Patient-specific aperiodic monitoring of temperature and blood pressure were determined by care requirements previously established on the floors.

The initial workflow for alerts included the remote telehealth center receiving immediate notification of critical events and investigating the sourcing alert data. If the alert was considered of clinical value, the telehealth center would either contact the patient directly via the two-way telepresence system (voice and video), contact the patient's nursing assistant (for technical events), or contact the patient's nurse via the in-building wireless phone system. For the 79 med/surg beds, the remote telehealth

group consisted of two experienced med/surg RNs who were trained in arrhythmia interpretation. The team monitors patients 24 hours a day, observing vital signs and test results to ensure appropriate care for medical and surgical patients. Additionally, they conduct daily "virtual" rounds on patients to review orders, test results, and discharge plans, and ensure that all appropriate evidence-based protocols are in place. When appropriate, they can communicate "face to face" with patients and staff in the patient's room through a two-way video system that includes a camera and monitor.

In order to quantify the alarm load for subacute med/surg floor patients, we automatically saved all physiologic data for later review. The data consists of all monitored waves as 125 samples per second (sps), 8 Bit. Most records include a single lead of ECG, impendance-based respiration via the ECG leads, and a photoplethysmogram (PPG) from the SpO_2 monitor. All alarm and event conditions declared by the monitoring system as well as 1 minute parameter trend data were permanently saved to an external server starting eight hours after admission, continuing until discharge (Research Data Export, Philips Healthcare). We analyzed data from all patients who were monitored on the floors between April 2009 and January 2010 (4,104 patients). We evaluated the physiologic data for alarm rates by parameter, severity, and validity based on an adjudicated subgroup of the population.

Results

In the telehealth center where only critical-level alarms were presented, the average number of alarms per patient per day observed by the remote user was 16.1 (s=44.6, median=4.4). Based on the size of the floor units, staffing ratios in the remote telehealth center, and average occupancy, this translates to an average alarm load of 42.3 (16.1*79*0.8/24) and median alarm load of 11.6 (4.4*79*0.8/24) per hour, assuming a unit occupancy of 80%. It is important to note that the median value of alarms per patient per day is only 4.4 while the standard deviation is almost 45. This clearly indicated a skewed distribution and suggests that a small number of patients created most of the alarm load for the users.

During the study period, a separate observational study was conducted to look at workflow, user satisfaction, and patient satisfaction with the test system. While this will be reported

Parameter Alarm	"True" criteria	"False" Criteria	"Uncertain" criteria
NIBP	(regular R-R as seen on ECG, or PPG waveform) AND (no significant ventricular ectopy) in the 60 seconds leading up to the measurement	(irregular R-R as seen on ECG, or PPG waveform) or (significant ventricular ectopy) in the 60 seconds leading up to the measurement	If the analysis of the data did not result in either aforementioned classification, or did not have any other corroborating data at the time of the event
SpO_2	(good PPG waveform at a constant signal level) AND (clear incisura or dicrotic notch) AND (no obvious motion artifact or noise) AND (ECG HR within 5% of PPG based Pulse).	(poor PPG waveform at an inconstant signal level) OR (no clear dichroic definition) OR (obvious motion artifact / noise) OR (ECG HR not within 5% of PPG based Pulse)	If the analysis of the data did not result in either aforementioned classification, or did not have any other corroborating data at the time of the event
Resp	(cardiac overlay <25%) AND (no significant noise or artifact on ECG) AND (no significant noise or artifact on RESP)	(cardiac overlay >25%) OR (significant noise or artifact on ECG) OR (significant noise or artifact on RESP)	If the analysis of the data did not result in either aforementioned classification, or did not have any other corroborating data at the time of the event
ECG and HR	(no significant noise or artifact on ECG) AND (good R-R correlation to PPG) AND (no significant noise or artifact on RESP)	(significant noise or artifact on ECG) OR (poor R-R correlation to PPG) OR (significant noise or artifact on RESP)	If the analysis of the data did not result in either aforementioned classification, or did not have any other corroborating data at the time of the event

Table 1. Adjudication criteria of alarms based on prior 30 seconds of physiologic wave and trend data. NIBP=noninvasive blood pressure; SpO_2=pulse oximetry; Resp=respiratory rate; ECG=electrocardiogram; HR=heart rate; R-R=ECG R to R wave interval; PPG=photoplethismogram

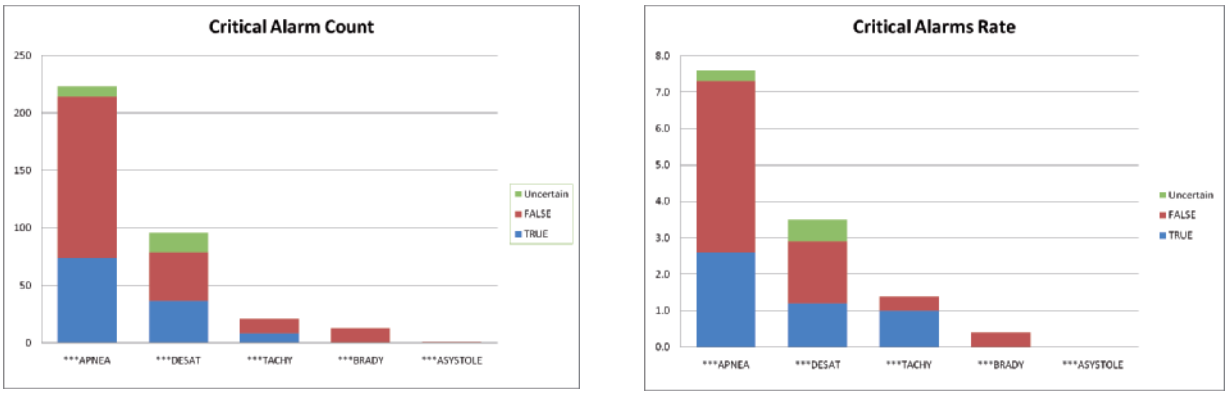

Figure 1. Ajudicated critical alarms; raw count and rate per patient, per day. (VT/VF=ventricular tachycardia/ventricular fibrillation; desat=desaturation; brady=bradycardia)

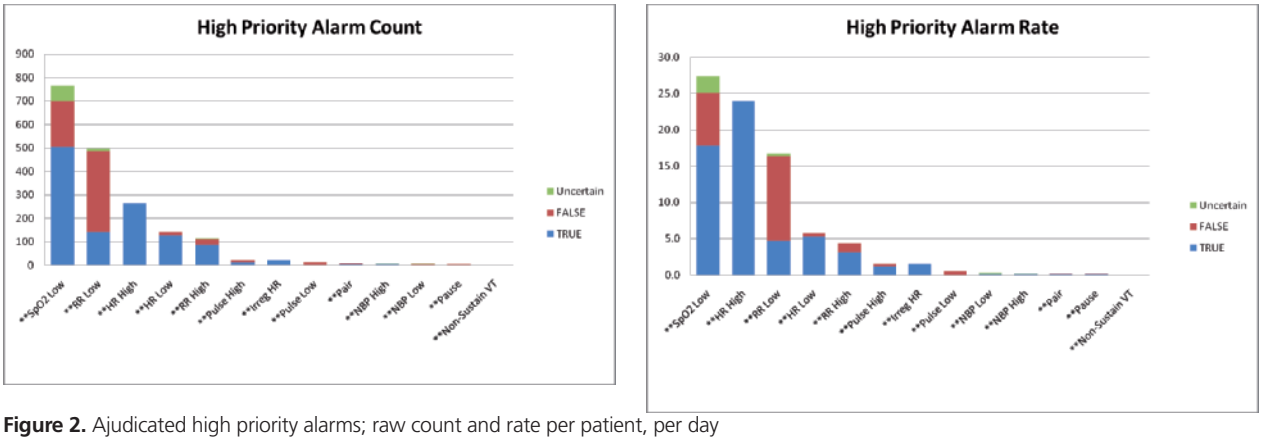

Figure 2. Ajudicated high priority alarms; raw count and rate per patient, per day

	Raw count				Rate (per patient, per day)		
Alarm	TRUE	FALSE	Uncertain	%True	TRUE	FALSE	Uncertain
***APNEA	74	140	9	33%	2.6	4.7	0.3
***DESAT	37	42	17	39%	1.0	4.5	0.0
***TACHY or VT/VF	8	13	0	38%	1.2	1.7	0.6
***BRADY	0	1	0	0%	1.0	0.4	0.0
***ASYSTOLE	0	1	0	0%	0.0	0.4	0.0
Total Critical	119	209	26	34%	5.8	11.7	0.9

Table 2. Critical alarm raw count and rate from ajudicated review (desat=desaturation; VT/VF=ventricular tachycardia/ventricular fibrillation; brady=bradycardia)

	Raw count				Rate (per patient, per day)		
Alarm	TRUE	FALSE	Uncertain	%True	TRUE	FALSE	Uncertain
**SpO_2 Low	505	196	64	66%	17.9	7.2	2.3
**RR Low	141	345	13	28%	4.7	11.6	0.4
**HR High	265	0	0	100%	24.0	0.0	0.0
**HR Low	128	13	0	91%	5.3	0.4	0.0
**RR High	87	25	1	77%	3.1	1.2	0.0
**Pulse High	13	9	0	59%	1.2	0.3	0.0
**Irreg HR	20	0	0	100%	1.5	0.0	0.0
**Pulse Low	0	14	0	0%	0.0	0.5	0.0
**Pair	4	4	0	50%	0.1	0.1	0.0
**NBP High	4	0	3	57%	0.1	0.0	0.1
**NBP Low	2	1	2	40%	0.1	0.0	0.2
**Pause	2	2	0	50%	0.1	0.1	0.0
**Non-Sustain VT	0	1	0	0%	0.0	0.0	0.0
Total High Priority	1171	610	83	63%	58.1	21.4	3.0

Table 3. High priority alarm raw count and rate from ajudicated review

separately, this study showed that the monitoring system was responsible for approximately 30% of the interruptions to care in the telehealth center. Of those monitoring-triggered interruptions, only 20% were true and clinically meaningful and resulted in a clinical intervention, such as the telehealth center asking the staff or patient to put the oxygen delivery device back on, for the staff to check or replace ECG electrodes, or for a change in care. To better understand this, we identified patients who were admitted prior to midnight the day before the observation days (n=63 patients) and adjudicated alarms (critical and high priority) on a randomly selected subgroup (n=30 patients). The alarm adjudication was based solely on the presence of the clinical event reported by the monitoring system and was not based on the actionability of the event based on evidence in the clinical record. During the observation period, 4,393 alarms resulted from 1,040.5 total monitoring hours, and 2,218 alarms were adjudicated from the resulting 529.5 hours based on the random sample. These alarms were reviewed by two independent clinical researchers for validity. In the case of disagreement, a third judge was utilized. Table 1 summarizes the validation criteria used.

Of the 2,218 total alarms reviewed, 354 were critical level and seen by the telehealth center. We also adjudicated the 1,864 high priority alarms recorded during this period. The critical- and high-level alarm adjudication results which were normalized to alarms/pt/

day are shown in Figure 1 and Figure 2 respectively.

There were a total of 13.1 critical alarms/patient/day (s =21.4, median =6.0) with 34% of these alarms being true based on alarm adjudication. Table 2 demonstrates the alarm with the greatest frequency was ***APNEA (average true rate = 2.6 , average false rate = 4.7; 33% True). This was followed by ***DESAT (average true rate =1.2, average false rate 1.7; 39% True) and by ***TACHY or V-TACH (average true rate =1.0, average false rate 0.4; 38% True). It should be noted that most of the *** TACHY alarms with heart rate over 160 are false. The breakdown for the 1,864 high-priority alarms, had they been announced to the user, was an average 82.5 alarms/patient/day (s=122.9, median =22.7) with 63 % of these alarms recorded as True. Table 3 demonstrates the alarm with the greatest overall frequency was **SpO_2 Low (average true rate =17.9, average false rate 7.2; 66% True).

While there are clearly opportunities for algorithm improvements to monitor these patients, we believe that today's ECG and SpO_2 technologies are viable to monitor this population. Additionally, we have seen several cases where arrhythmia monitoring resulted in new actionable clinical knowledge. However, the positive predictive value of this monitoring is low. Based on the relatively low pre-test likelihood, and the fact that only a single vector of ECG is monitored in this environment, we recommend a patient risk-based approach rather than blanket arrhythmia monitoring in the sub-acute care areas. At the very most, we would recommend using only limited or basic arrhythmia monitoring. We further conclude that while the sensitivity of impedance respiration may be too high for this population, the parameter does provide value in this setting based on the raw true alarm count. The raw number of true apnea alarms indicates that this may be a useful screening application for sleep apnea and hypopnea.

SpO_2 high priority and critical alarms are linked by a SpO_2 offset level and persistence delay. Similarly HR high and critical alarms are linked by a delta HR level. This implies two items. First, alarms shown in Figures 3 and 4, which annunciated below the severe SpO_2 value of 80% or above the severe high HR of 140

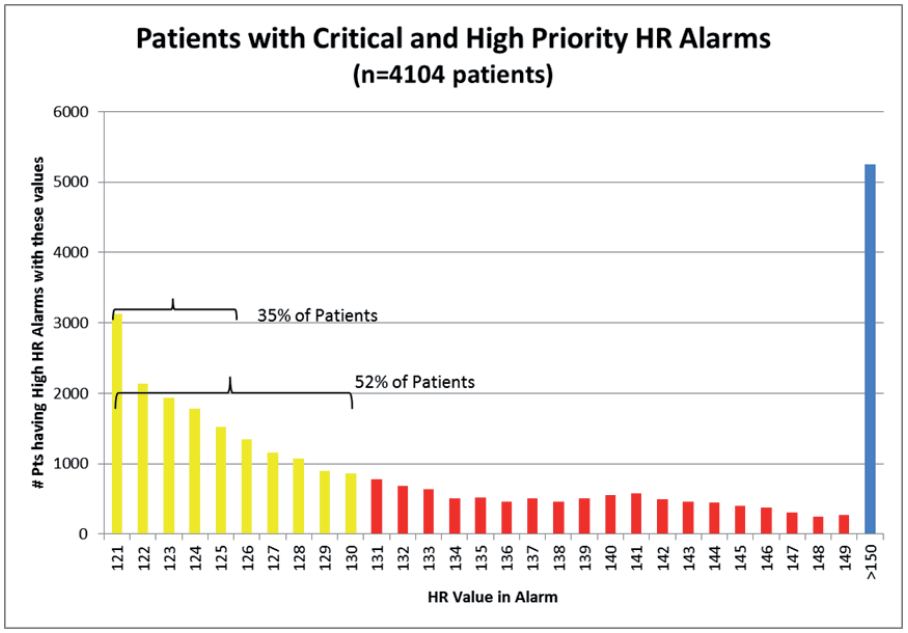

Figure 3. Number of patients with high heart rate alarms

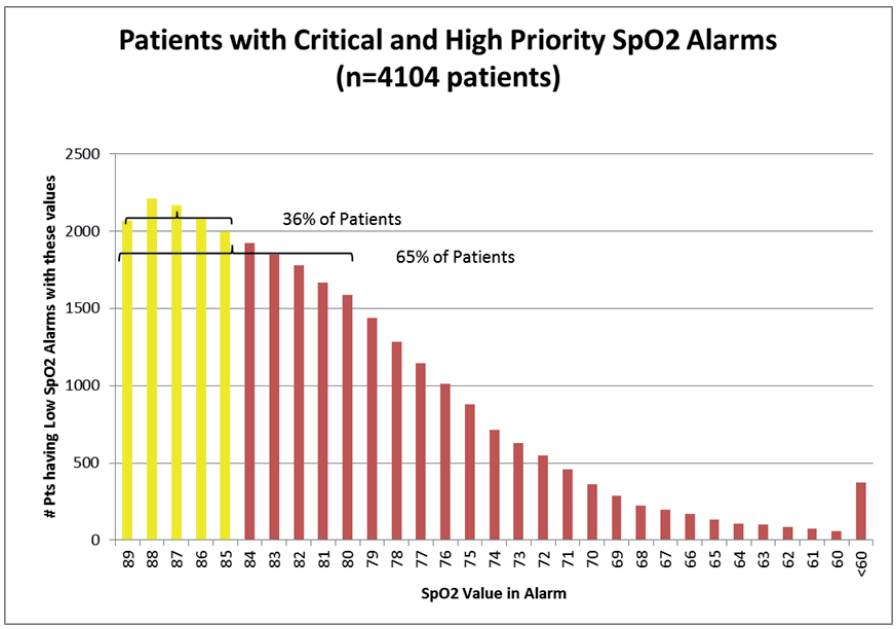

Figure 4. Number of patients with low SpO_2 alarms

bpm, are critical alarms. And second, by moving the low SpO_2 and high heart rate "high priority" limit, there will be a concurrent reduction of the severe alarms.

The frequency of critical and high priority alarms is predominately caused by two or three specific alarms in each priority. Further, analysis of alarm history resulted in the ability to reduce the high HR alarm load by 35% by increasing the default limit adjustment of high HR from 120 to 125 bpm, and by 52% with a simple limit adjustment of high HR from 120 to 130 bpm (assuming the severe tachy limit stays at 130). A 36% reduction in SpO_2 alarm load will be seen by reducing the high priority SpO_2 limit from 90% to 85% and further reducing the critical SpO_2 65% with a limit reduction from 90% to 80% (assuming the severe desaturation alarm stays at 80%).

Unfortunately the duration of physiologic events is not easily extracted from the data, and time correlation to therapy analysis is ongoing. A sustained SpO_2 of 80% was not accepted by this clinical community as an acceptable alarm limit; however others have found a low and persistent SpO_2 alarm at 80% acceptable.[8]

Clearly these are very simple changes that significantly reduce the raw number of critical and high-priority high HR and low SpO_2 alarms. Work is underway to ascertain the sensitivity and specific of these new alerts limits related to clinical interventions and actual patient deterioration.

Conclusion

Standard critical care alarm limits may be too sensitive for subacute care areas of the hospital, but alarm loads can be controlled with limit setting starting first with limits appropriate to the population and then possibly from fine tuning to the specific patients who create excessive false or non-actionable alarm loads. ■

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