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Impact of Pulse Oximetry Surveillance on Rescue Events and Intensive Care Unit Transfers

A Before-and-After Concurrence Study

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ABSTRACT

Background: Some preventable deaths in hospitalized patients are due to unrecognized deterioration. There are no publications of studies that have instituted routine patient monitoring postoperatively and analyzed impact on patient outcomes.

Methods: The authors implemented a patient surveillance system based on pulse oximetry with nursing notification of violation of alarm limits *via* wireless pager. Data were collected for 11 months before and 10 months after implementation of the system. Concurrently, matching outcome data were collected on two other postoperative units. The primary outcomes were rescue events and transfers to the intensive care unit compared before and after monitoring change.

Results: Rescue events decreased from 3.4 (1.89–4.85) to 1.2 (0.53–1.88) per 1,000 patient discharges and intensive care unit transfers from 5.6 (3.7–7.4) to 2.9 (1.4–4.3) per 1,000 patient days, whereas the comparison units had no change.

Conclusions: Patient surveillance monitoring results in a reduced need for rescues and intensive care unit transfers.

What We Already Know about This Topic

- ❖ Early recognition of deterioration is essential for early intervention to prevent cardiac or respiratory arrest
- ❖ Universal surveillance for such early recognition has not been applied to postoperative patients

What This Article Tells Us That Is New

- ❖ Implementation of universal surveillance with pulse oximetry was associated with a reduced need for patient rescue and intensive care unit transfers

THE major focus on reducing perioperative morbidity and mortality has been on identifying and reducing risk factors for anesthesia and surgery. Much less emphasis has been placed on the postoperative period. Our interest has been to detect deterioration that occurs in the general care setting where the staff is immediately available to intervene but is unaware of the deterioration.

Medical emergency teams have been recently introduced to address the problem of late intervention in recognition when patients show signs of deterioration in the 6–8 h before a cardiac or respiratory arrest.[1–6] Early recognition of patient deterioration has been identified as the primary determinant of the success of early intervention with medical emergency teams.[7] The results of these early intervention efforts have been mixed, and only weak evidence has been found that they benefit patients.[8,9]

We implemented a patient surveillance system (PSS) in the postoperative care setting that used continuous pulse oximetry to facilitate early recognition of deterioration and cue rescue interventions. The surveillance system alerts the patient's nurse *via* pager when preset physiologic parameter alarm settings are violated.

This is the first published report of surveillance (100% monitoring of patients during their entire hospitalization when not directly observed by the healthcare team) rather

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◆ This article is accompanied by an Editorial View. Please see: Abenstein JP, Narr BJ: An ounce of prevention may equate to a pound of cure: Can early detection and intervention prevent adverse events? ANESTHESIOLOGY 2010; 112:272–3.

Table 1. Demographics of the Three Units

Unit	Mean Age	% Females	Most Common DRG
PSS unit	56.7	50	Major joint procedure
Comparison unit 1	56.8	59	Uterine and adnexa procedure
Comparison unit 2	61.1	55	Major chest procedure

DRG = diagnosis-related group; PSS = patient surveillance system.

than condition monitoring in postoperative clinical practice. It is a new approach to detect unrecognized postoperative deterioration, a significant precursor in morbidity and mortality for in-hospital patients.[10] The PSS was designed to maximize patient and nurse acceptance, minimize false positive alarms, and only alert for clinically meaningful situations (actionable events).

Materials and Methods

Setting

The PSS was implemented in a 36-bed orthopedic unit with an average of 200 patient days and 53 patient discharges per week. Nurse to patient ratio was 1:5 with a mostly elderly population undergoing joint replacement surgery with significant use of postoperative opioids. After evaluating different systems, the Patient SafeyNet (Masimo, Irvine, CA) was chosen because of its motion artifact performance, configurability, and ability to perform direct nurse notification. Patient SafetyNet uses wireless communications to connect bedside pulse oximetry (Spo_2) monitors (using disposable finger probes) to a server computer and a radio transmitter that notifies nurses *via* pager when physiologic limits are violated. The comparison units for this study were two surgical units caring for urologic, gynecologic, and vascular and general surgical patients (table 1). None of the three units had a routine monitoring system in place, except for condition monitoring (selective monitoring of patients perceived to be at high risk for adverse events based on health conditions using cardiotelemetry).

Policies and procedures at Dartmouth Hitchcock Medical Center at the time of implementation included a tiered response system for first responders managing medical emergencies and urgent situations. Our life safety program consists of three rescue teams (emergent to urgent): (1) code blue, (2) STAT airway, and (3) Hitchcock Early Response Team (HERT). All teams have the capacity to respond to adult, pediatric (defined by less than 12-yr old), and neonatal patients. It is the role of these teams to provide emergency medical intervention such as code blue response or establishment of an artificial airway, to provide consultation to a referring team when a patient experiences early deterioration or triage patients to a higher level of care, and to facilitate transport of the patients to an appropriate unit. It is our standard of care and expectation that nurses, physicians, and all other healthcare professionals within the organization will activate the appropriate team based on the patient's presentation as outlined in the Life Safety Policies.

Code blue teams are to be activated when a victim is found in cardiopulmonary arrest (no pulse and/or respirations). The code team is to be activated for all cardiopulmonary arrests in all areas with the following exception: if the code is located in the operating room, the cardiac catheterization laboratory, electrophysiology laboratory, and the critical care units, the attending physician, if physically present, may opt out of activation of the code team. Activation of the code teams provides logistic support in addition to quality emergency support. This includes the administrative coordinator on site transportation services, security, chaplin, and stores, which bring an additional code cart, a medication box with spare first line advanced cardiac life support medication, and intravenous pumps.

STAT airway teams are to be activated for patients in need of an urgent intubation but who have a stable heart rate and blood pressure. The STAT airway team does not have to be activated if an expert airway provider (anesthesia) is immediately available for the intubation.

HERT provides critical care resources (Critical Care Registered Nurse and Respiratory Care Provider) to patients in noncritical care areas when any patient demonstrates early signs of deterioration and crisis. Any member of the healthcare team including the patient's family can activate the HERT team. No healthcare provider is to discourage or prohibit the use of the HERT teams. When the HERT team is activated, the patient's primary team (if not already present) is to be called and notified that the patient has had an activation. HERT will act in collaboration with the patient's primary care teams to assess the patient, develop appropriate plans of care, and provide treatment interventions as needed. Physiologic criteria used for activation include the following:

- heart rate more than 130 or less than 40 beats per minute,
- systolic blood pressure less than 90 mmHg,
- respiratory rate less than 8 or more than 30 breaths per minute,
- Spo_2 less than 90% with supplemental oxygen,
- acute mental status changes,
- difficulty in speaking,
- threatened airway, and
- staff member concern about patient.

After activation, an adult critical care registered nurse and a respiratory care practioner are to arrive at the patient's bedside within 10 min. They communicate with a member of the critical care services team to determine whether a critical care service provider is needed at the bedside or whether a higher level of care is necessary.

Anesthetic Technique

Although the study did not control for the anesthetic technique used, there was no appreciable change. The number of

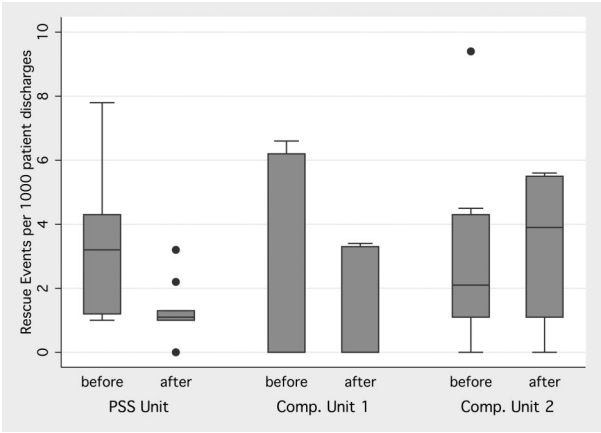

Fig. 1. Rescue events per 1,000 patient discharges before and after. PSS = patient surveillance system unit. Plot elements: *filled circles* = outside values; - = adjacent value; +–+ = top and bottom of box are twenty-fifth and seventy-fifth percentiles; — = median.

regional blocks performed was 159.6 and 160.9 per month in the presurveillance and postsurveillance period, respectively, and femoral nerve blocks were 50.2 and 51.8, respectively, per month. Neither was there a significant change in the percentage of femoral nerve catheters used; 18.8 and 20.5% of femoral blocks used a catheter. The same was true for other blocks performed. Patient satisfaction with pain control was similar on the study unit in the before and after periods (86.6 before and 84.1 after in the study unit on a 0–100 scale), further indicating similar pain control *via* similar intraoperative and postoperative analgesic management.

Implementation

After approval by the Committee for the Protection of Human Subjects (Dartmouth College, Hanover, New Hampshire) for consent waiver, implementation, and data analysis, the Federal Drug Administration-approved Patient SafeyNet was implemented to continuously monitor all patients when not in direct contact with clinical staff. The major concepts of the surveillance net were alarm thresholds and notification delay. Careful calibration of alarm triggers is essential in finding a balance between high sensitivity and number of false alarms. Based on a month of observed physiology, an alarm trigger typically selected for monitoring patients (in the operating room, sedation, or selective patient monitoring) with Spo_2 of less than 93% would have frequently been in alarm state. Our postoperative patients spent more than 12% of the observed data points at levels lower than 93%. This 12% includes not only dangerous deteriorations but also short, self-correcting dips and false readings. Alarming for all these cases is appropriate in a 1:1 procedure care setting when a provider's full attention can be directed to identifying and responding to legitimately dangerous conditions. However, in a general care setting with a 1:5 nurse to patient ratio, an alarm redirects nurse attention from other important tasks, and a high frequency of alarms will desensitize staff, leading to delayed responses (an earlier trial run on another unit with a different configuration generated several false alarms per patient per hour, and nurse response times quickly dropped until many alerts were simply ignored). Therefore, it is necessary to trade off earlier notification of some deterioration against limiting the nuisance alarms generated by self-correcting changes or false readings. To reach a balance between actionable and false positive alarms in this work, the following alarm thresholds were chosen: Spo_2 less than 80% (fig. 1) and heart rate less than 50 and more than 140 beats per minute.

Although these limits are appropriate for most situations, some patients have abnormal baseline physiology (such as chronically low oxygen saturation due to chronic obstructive pulmonary disease). This can lead to alerts that are true indications of physiology but are not clinically actionable. Therefore, a three-tier system was implemented to allow for parameter adjustment: (1) standard setting, (2) bracketed adjustment (±10% of baseline) by nursing staff, and (3) physician-ordered settings. Patients generally begin with standard settings, but in abnormal baseline cases, nursing staff can adjust the thresholds to alert on deviations greater than 10%. Physicians also have the ability to order specific limits for unique situations.

Notification delay is the other important concept in alarm frequency management. Appropriate delay eliminates many transient and motion artifact-generated false alarms. We instituted a 15-s audio alarm delay at the bedside and an additional 15-s delay for pager annunciation, leading to a 30-s delay before a nurse would be notified by pager of violation of alarm thresholds (this was the system maximum delay).

Table 2. Patient Volume and Acuity Index of the Three Units

Unit	Patient Discharges (n)		Patient Days (n)		MS-DRG Index	
	Before	After	Before	After	Before	After
PSS unit	3,118	2,841	9,978	9,092	1.93	1.92
Comparison unit 1	1,260	1,162	3,462	3,139	1.52	1.53
Comparison unit 2	2,628	2,389	9,724	8,841	2.36	2.22

Before and after is relative to introduction of the PSS.
MS-DRG = medicare severity diagnostic-related groups; PSS = patient surveillance system.

Table 3. Rescue Events (Mean ± SD, 95% CI) per 1,000 Patient Discharges Before and After

	Rescues Before	Rescues After	*P* Value
PSS unit	3.4 ± 2.2 (1.89–4.85)	1.2 ± 0.94 (0.53–1.88)	0.01
Comparison unit 1	2.0 ± 0.88 (0.05–4.0)	1.3 ± 1.68 (0.1–2.50)	0.5
Comparison unit 2	2.7 ± 0.82 (0.87–4.51)	3.4 ± 0.67 (1.87–4.9)	0.53

CI = confidence interval; PSS = patient surveillance system.

Training was provided to approximately 60 nurses covering all shifts. This training included in-service training on system use provided by the manufacturer, a discussion of the problem of unrecognized deteriorations, a description of the alarm threshold policy, and 2 weeks of daily rounding by clinical leadership designed to identify and correct problems. No additional staff was added to the existing care team.

Data Collection

Data were collected prospectively hospital wide. No change of data collection was performed during the study period. Data include, but are not limited to, STAT airways, code blue, HERT activation, transfer to the intensive care unit (ICU), death, patient demographics, patient diagnosis related group, length of stay, and patient satisfaction with pain control. Regional anesthetics are tracked in a separate database maintained by the regional anesthesia group.

Data Analysis

Data were analyzed before and after the intervention for the PSS unit and compared with two other units that care for surgical patients. The before time frame consisted of 11 months from January 1, 2007, to November 30, 2007, and the after time frame of 10 months from December 1, 2007, to September 30, 2008. Data were collected for the PSS unit and the comparison units during the same time (table 2). Absolute changes in outcome numbers (effect sizes) were annualized for before and after introduction of the PSS to make them comparable and easier to interpret.

Rescue events were a combination of codes, STAT airway, and HERT alerts. All alerts were reviewed, and only alarms meeting the trigger criteria described earlier were recorded in the database as rescue events. For comparison purposes, rescue events were tracked as per 1,000 discharges (as done by the Institute for Healthcare Improvement) for the PSS and comparison units. Transfers to the ICU were tracked as transfers per 1,000 patients days for all units (as the most commonly used denominator for patient transfers). All data outcomes were compared with *t* tests using STATA 10 (College Station, TX). R‖ was also used to analyze and display more than 1.5 × 1,000,000,000 data points from the server. Data are graphically displayed as box plots.

Results

The system had a very high patient acceptance rate of 98.2% (1.8% patients refusing to continuously wear a pulse oximeter because of inconvenience). System uptime was 99.9995%. The number of alarms averaged four per patient per day or two per 12-h nursing shift. Observed deaths after implementation were two as opposed to four in the previous time frame. These include both deaths on the ward and after transfer to ICU. Length of stay were 3.69 and 3.68 days (not significant) for all patients and 3.29 (3.18–3.39) and 3.20 (3.11–3.29) days (not significant) for patients who did not have an ICU transfer for the before and after periods. Rescue events in the PSS decreased from 3.4 (1.89–4.85) to 1.2 (0.53–1.88) per 1,000 patient discharges after implementation of the system, while changing from 2.0 (0.05–4.0) to 1.3 (0.1–2.50) and 2.7 (0.87–4.51) to 3.4 (1.87–4.9) per 1,000 patient days for the comparison units, respectively (fig. 1; table 3). Transfers to the ICU declined from 5.6 (3.7–7.4) per 1,000 patient days to 2.9 (1.4–4.3) (fig. 2), whereas the two comparison units changed from 5.7 (2.1–9.2) to 5.2 (2.2–8.2) and 15.0 (11.1–18.9) to 12.7 (10.0–15.3) per 1,000 patient days (table 4).

Discussion

The primary finding is that early detection of deterioration of physiologic parameters (Spo_2 and heart rate) in the PSS unit led to fewer rescue events and a decreased need to escalate care. Deployment of the PSS was associated with a significant drop of rescue calls from 3.4 to 1.2 per 1,000 patient discharges ($P = 0.01$). In our 36-bed unit, this means an effect size change from 37 to 11 rescue events annualized. ICU

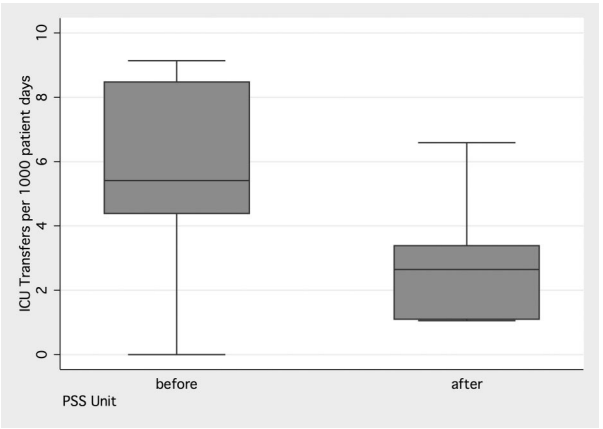

Fig. 2. Transfers to ICU on the PSS unit per 1,000 patient days before and after implementation. ICU = intensive care unit; PSS = patient surveillance system. Plot elements: - = adjacent value; +–+ = top and bottom of box are twenty-fifth and seventy-fifth percentiles; — = median.

‖ http://www.r-project.org/. Accessed October 23, 2009.

Table 4. Transfers to the ICU (Mean ± SD, 95%CI) per 1,000 Patient Days before and after PSS Implementation

Unit	ICU Transfers Before	ICU Transfers After	*P* Value
PSS Unit	5.6 ± 2.8 (3.7–7.4)	2.9 ± 2.0 (1.4–4.3)	0.02
Comparison Unit 1	5.7 ± 1.6 (2.1–9.2)	5.2 ± 1.3 (2.2–8.2)	0.8
Comparison Unit 2	15.0 ± 5.7 (11.1–18.9)	12.7 ± 3.7 (10.0–15.3)	0.3

CI = confidence interval; ICU = intensive care unit; PSS = patient surveillance system.

transfers declined from 5.6 to 2.9 per 1,000 patient days; over 1 yr, this equates to a decrease from 54 to 28 transfers. With an average length of stay of 5.2 days for patients transferred to ICU, this saves our institution 135 ICU days per year from this 36-bed unit alone. Patients on the PSS unit who are transferred to the ICU have an average hospital stay of 25.3 days as opposed to 3.2 days when not transferred. Overall, ICU transfers are relatively rare events that do not change length of stay significantly.

Although we observed a decrease in mortality, we do not think that the change is meaningful because of the small number effect due to the low baseline rate of postoperative death. We expect to have more powerful data in approximately 15 months from now after expanding implementation to another 85 postsurgical beds.

The current standard of care for hospital inpatients is the sampling of intermittent vital signs and clinical examinations with additional condition monitoring for patients considered to be at high risk for adverse events. The patient surveillance group at Dartmouth (a collaboration of the Thayer School of Engineering and Dartmouth Hitchcock Medical Center) has conducted empiric and engineering research for years[11,12] using continuous monitoring of pulse oximetry to automate patient state classification and the detection of physiologic deterioration based on field triage algorithms such as START[13] and the Sacco method.[14] The system was designed to assist medical personnel in resource-constrained environments, such as working conditions in which nursing ratios allow for only intermittent monitoring, because it is the case in most hospitals.

The technology underlying the PSS is sound, but simply identifying physiology is not sufficient in surveillance monitoring—it is also necessary to address the problem of resource utilization. Low nurse–patient ratios demand a different balance of sensitivity and specificity when compared with the operating room. Continuous patient surveillance can only be successful if it is not a burden to the already limited personnel resources, and thus, thoughtful implementation of the technology is the key.

Many false positive alarms (nuisance alarms) will lead staff to become desensitized, as observed in a previous trial run. In contrast, the current work demonstrates that meaningful, clinically actionable alarms will lead to rapid system acceptance and adoption by the nursing staff. Although the alarm limits are clearly different than those typically used in the operating room, ICU, or condition monitoring situation—and might appear counter intuitive—they are based on the fundamentally different approach of triaging and surveillance monitoring in the general care setting.

Before-and-after studies such as ours are frequently limited by confounding from change of environmental variables, for example, change of clinical practice and learning effects. Changes in clinical management or quality improvement interventions typically occur on a hospital or ward level, and it is frequently not practical to run concurrent protocols. In these settings, it is typical practice to analyze changes in before-after fashion, just as changes in healthcare delivery models are compared by region or cluster analysis. In both instances, the target of interest is not one single individual, but a group—in this instance, postoperative orthopedic patients. Before-and-after studies are primarily weakened by temporal trends or changes that occurred independent of the intervention. In our study, for example, a significant change in the use of regional anesthesia, increase of nurse–patient ratio or an increase of physician coverage could have resulted in outcome changes independent of the system implementation. We carefully monitored for these confounders and tracked all data prospectively before and after the change. Furthermore, we strengthened our methodology by comparing outcomes with two other units in the same time frame to monitor for environmental changes that might have occurred across all three units. Data in the two comparison units was prospectively gathered at the same time as in the study unit. All units did not have operational changes in nurse–patient ratio or any intervention protocols, nor did any of the rapid response teams. Staff on all three floors was aware of the ongoing data collection, so that any changes due to the Hawthorne effect (where performance improves in the presence of observation) should be similar across the dataset.

The training received by the members of the PSS unit was limited to the use of the new technology and did not introduce any new general interventional or diagnostic technique. The most common nursing comment is of a sense of increased knowledge about the status of their patient based on the Spo_2 and heart rate information visible on the in-room monitor, reinforcing the likelihood that any increased nursing attention is a direct result of the new system, not a by-product of the implementation process.

Although monitoring systems other than continuous pulse oximetry such as carbon dioxide or respiratory rate monitoring are available, we have found in several pilot studies with these devices that patient tolerance and compliance are too low for them to be used as continuous monitors in the ward setting.

In conclusion, our results demonstrate that continuous patient surveillance can improve outcomes in a postoperative orthopedic ward setting. Preliminary data from a 6-month rollout to the previous comparison units used in this study indicate that these findings may hold true for other postoperative settings as well.

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