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Continuous Pulse Oximetry Monitoring in the Inpatient Population

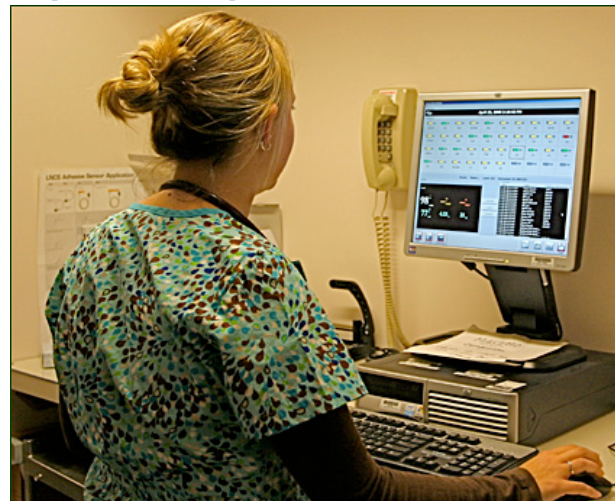


Photo Courtesy of Nancy Karon

By **Josh Pyke, BE; Klaus Christoffersen, PhD; Jean Avery, MBA, BSN; George T. Blike, MD; Susan P. McGrath, PhD; and Nancy Karon, RN, BSN, ONC**

John Smith is admitted late Monday afternoon to the post-surgical ward after a total knee replacement. John is overweight, though not morbidly obese, and has an undeclared history of snoring. He wakes up at 5:30 Tuesday morning with considerable pain; over the next hour he exhausts the opiate supply in his PCA pump, and his nurse inserts a new syringe before her shift ends at 7 a.m. It will be more than 45 minutes before John is next checked by the nurse starting his day shift — plenty of time for John's high dosage of opiate analgesics, exacerbated by his undiagnosed sleep apnea, to send him dangerously deep into respiratory depression.

Similar scenarios play out daily at hospitals across the country, leading to increased length of stay, costly ICU admissions, and even preventable patient deaths. Patients under moderate sedation can deteriorate rapidly due to respiratory depression, airway obstruction, etc. In many procedural settings, such as colonoscopy, this risk is managed with individual attention from a highly-trained nurse and continuous physiological monitoring. However, floor nurses in a surgical ward routinely manage multiple patients at an equivalent level of sedation for days at a time, with vitals checks occurring only every several hours.

Automated electronic physiological monitoring presents a possible solution to this safety gap, but high cost and high false alarm rates have prevented its widespread acceptance



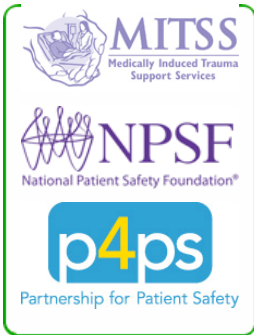
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to date. One institution's experience with a new pulse oximetry-based system, combined with careful implementation and optimization strategies, suggests that it is possible to mitigate these shortcomings and bring about a sustainable increase in patient safety.

For patients like John Smith, this extra protection is critical. His continuous pulse oximetry monitor identifies his deep desaturation and alerts the nurse coming on duty. The respiratory depression is reversed without intubation, and John is able to avoid an increased length of stay on the inpatient ward.

The Setting

At Dartmouth-Hitchcock Medical Center (DHMC) in Lebanon, New Hampshire, the new monitoring system has been implemented on a 36-bed inpatient ward primarily handling orthopedic surgery, as well as trauma and plastic surgery. Nominal nurse-patient ratio is 1:5, with beds laid out in a pod structure that increases patient privacy but makes direct observation by clinical staff more difficult. The focus on orthopedics, and particularly joint replacement, means that many patients are on high levels of opiate analgesics for extended periods — making the ward an ideal setting for an early-detection safety initiative.

The System

DHMC uses a pulse oximetry-based floor monitoring system with direct nurse notification via pager specifically designed for the general floor environment. Standard bedside pulse oximeters communicate over the hospital's wireless infrastructure, connecting to a computer server and admitting station (Figure 1). Nurses receive direct notification via pager when an alarm condition is violated. The default definitions of these alarm conditions are configurable by biomedical engineering.

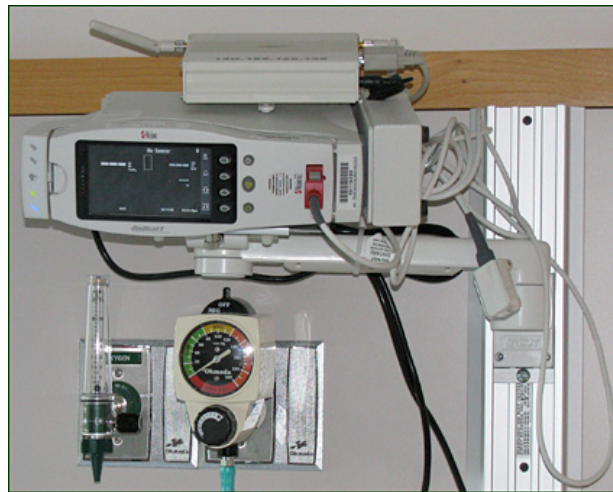


Figure 1. Rad-7 oximeter installed at bedside

Photo Courtesy of Joshua Pyke

Clinicians use the nursing station to admit, discharge, and modify alarms for their patients. When a patient violates an alarm condition, a page is first sent to that patient's nurse; if the condition is not corrected within 2 minutes, a secondary page is sent to the second nurse on the pod, as well as the resource nurse on duty.

The PSN system works with any oximetry probe fitting the bedside oximeter unit (Figure 2). It is important to avoid spring-loaded clip-style probes for surveillance monitoring, as they carry a risk of pressure necrosis, generate more false alarms, and introduce a source for infection. The trial unit began with adult disposable probes, before switching to micropore tape probes, which were found to offer better adhesion over time. Velcro probes are also in use, which are more compatible with the frequent washing required by a hand hygiene initiative on the unit.



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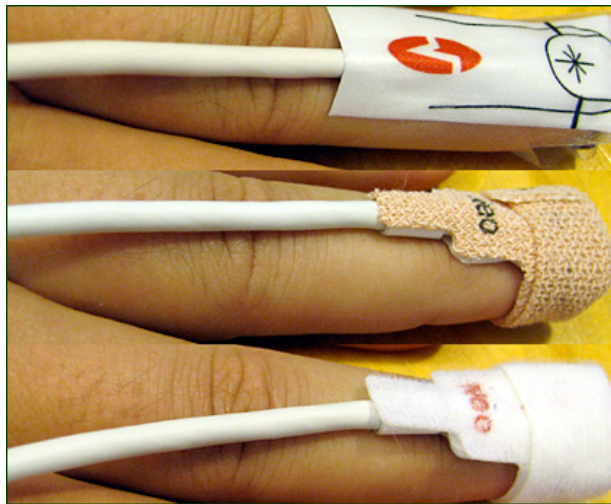


Figure 2. Three probe types used in trial

Photo Courtesy of Joshua Pyke

The Process

Managing early detection and response takes cooperation from multiple disparate entities, both inside and outside the hospital. At DHMC, the major stakeholders are:

- Industry: designs and builds technology.
- Biomedical engineering: installs and configures technology.
- Clinical leadership: designs and implements monitoring policy, procedure and practice.
- Nursing staff: carries out monitoring; interacts with technology.
- Rapid response team: often called to respond to deterioration events.
- Doctors: write monitoring orders, determine treatment plans.

In order to make sure that a monitoring solution took all of these viewpoints into account, planning meetings for the new monitoring system included representatives from all of the above groups. This enabled a holistic design process, which was able to uncover and address issues from all elements of the early detection system, from installation to event detection to event response.

Human factors engineers also participated in the design process, first by studying the practices already in place on the target unit, then through input to the design and implementation process, and finally by observing the new system as it was put in place. These observations inform implementation planning for new installations of similar systems.

A key observation from prior floor monitoring experiments at DHMC was the problem of oversensitivity: when a monitoring system generates a high number of false positives, nursing staff begins to ignore the alarms, and the system loses almost all utility. In order to prevent this process, a target was chosen of one false alarm per patient per shift.

Reducing false alarms requires optimization of each component within the end-to-end system. The sensor selection and application must take into account the unique setting of general patient care. Single use disposables are preferred in order to minimize false alarms due to patient movement and meet infection control objectives. The bedside device must mitigate false alarms with measure-through-motion algorithms as well as provide an easy to use interface for the nursing staff. Connectivity to the bedside device must be both highly reliable and affordable so the system is scalable throughout the hospital. Alarm notification to the assigned nurse must filter non-treatable events from those that require urgent intervention. The entire system must be a trusted tool that enhances the normal work flow within the general care environment.

Alarm conditions for this trial were chosen with this goal of false alarm mitigation in mind. False readings in pulse oximetry often come as brief spikes due to patient motion or other factors. For example, a patient repositioning him- or herself in bed may grab a trapeze that momentarily obstructs blood flow to the finger on which the sensor is placed, causing a brief, localized but non-treatable drop in oxygen saturation. Averaging can help to mitigate these spikes, but excessive averaging reduces the responsiveness of the monitor signal to real physiological changes. In addition to configurable averaging, the system has the ability to delay audio annunciation of alarms both at bedside and

prior to issuing an alarm page. Delays at the bedside reduce noise within the patient room from non-actionable alarms and thereby improve the patient care environment. Additional delays within the system allow a nurse in proximity to the patient to respond before an alarm page is initiated. Using a 30-second delay (15 seconds at bedside and an additional 15 seconds before paging) was found to drastically reduce the number of non actionable alarms transmitted to nurses. With the only pre-existing physiological monitoring being 4- or 8-hour vitals checks, even this relatively low-sensitivity alert setting represents a major improvement.

Similarly, while procedure-level patient monitoring often uses very tight physiological thresholds in order to identify minor deviations from baseline, surveillance monitoring can use looser limits which, when violated, raise the probability of a legitimate deterioration significantly. For this trial, the oxygen saturation lower alarm limit started at 75%. After a week of testing, this was raised to 80%, which has yielded a good balance of sensitivity and specificity for the surveillance monitoring environment. Heart rate limits were set at 50 and 140 beats per minute. While extreme, these alarm thresholds are appropriate for interrupting a busy nurse.

Posters and presentations during the design phase helped communicate to the nursing staff that their feedback would be used to tune the technology during installation and would ultimately determine whether it would stay in place long term. This was reinforced with a month-long period of daily rounding by clinical and technical staff. Directly soliciting feedback from clinicians, rather than waiting for them to take the initiative, yielded valuable insights into the strengths and weaknesses of the technology.

Preliminary Results

The trial at DHMC has shown that floor-wide pulse oximetry-based surveillance monitoring can feasibly be implemented using current technology. Critically, there have been only about four alarms per patient per day, which approaches the goal of one per patient per shift. Nursing satisfaction has been very high: front-line staff were overwhelmingly in favor of keeping the system after the initial trial period.

Rapid-response activations have dropped significantly, which the team attributes to improved ongoing awareness of patient state. Fewer patients have been transferred to intensive care because clinicians are responding to early warning indicators identified by the system — nurses often use the term "drift" to describe a slow deterioration detectable over the course of a couple hours, even before alarms have been tripped. A wide array of physiologic deteriorations has been noted, including preliminary indications for several that are not commonly associated with pulse oximetry: poor heart rate control, acute bradycardia needing atropine, new onset atrial fibrillation, and pulmonary complications such as fat emboli syndrome, pulmonary embolus, and pulmonary edema. It is hypothesized that longer-term data will demonstrate improvements in length-of-stay and patient throughput resulting from the early detection and treatment of these conditions. Anecdotal evidence already exists for improved length-of-stay in individual cases, such as the use of the low saturation alarm as a reinforcement tool for incentive spirometry use.

One unanticipated effect is new diagnoses identified by the system. Many obstructive respiration patterns, likely undiagnosed sleep apnea, have caused repeated alarms at night and led to increased collaboration with the on-site sleep lab. In the extreme case, discovery of previously-undiagnosed respiratory irregularities can delay placement of post-operative patients into recovery care. Nurses also identified some usability difficulties with the system, particularly associated with the specific pagers used in this trial. This feedback is being used by the company to improve human factors within the system.

Conclusions

Overall, the trial has been a solid success, and DHMC plans to install the system at other sites in the institution. The lessons of the trial, particularly in the importance of understanding the existing practices, limitations and priorities of new sites, serve as a useful guide for future implementations.

Technology Overview

The system implemented at Dartmouth-Hitchcock Medical Center is Masimo's Patient SafetyNet (PSN) system with Radical-7 bedside pulse oximeters.

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