Capnography Monitoring Enhances Safety of Postoperative Patient-Controlled Analgesia

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Background: Patient-controlled analgesia is associated with potentially fatal opioid-related respiratory depression. Opioids are a well-recognized cause of respiratory depression. However, in the postoperative patient, unrecognized pulmonary disease may lead to retention of carbon dioxide, which is further antagonized by opioids and may lead to life-threatening respiratory depression. Therefore, using a method that would provide earlier warnings for respiratory problems could improve patient outcomes.

Objective: To assess the efficacy of monitoring postoperative patients who were receiving patient-controlled opioid therapy with capnography modules in addition to the routine use of pulse oximetry to monitor ventilatory status and generate alerts when respiratory parameters exceed hospital-established limits.

Method: Postoperative patients receiving patient-controlled analgesia were compared in relation to the use of pulse oximetry and capnography modules and their ability to generate alerts about abnormal respiratory parameters. A total of 634 patients receiving patient-controlled analgesia therapy were studied, of whom 239 (38%) received hydromorphone, 297 (47%) received morphine, and 98 (15%) received fentanyl. All 9 patients experiencing respiratory depression received supplemental oxygen.

Results: Of the 634 patients studied, 9 (1.4%) experienced respiratory depression by bradypnea (<6 breaths per minute). Six (67%) events were related to hydromorphone and 3 (33%) were related to morphine. In 7 (78%) events, there was no basal infusion rate and the saturation of peripheral oxygen was >92%. All respiratory depression events occurred within the first 24 hours of patient-controlled analgesia therapy. In all cases, capnography, but not pulse oximetry, alerted the nurse to impending respiratory depression.

Conclusions: Capnography was more effective than pulse oximetry in providing early warning of respiratory depression in patients receiving supplemental oxygen. Capnographic monitoring and automatic pausing of patient-controlled analgesia improved postoperative outcomes in situations that could have otherwise been fatal. Use of capnography improved clinician confidence that opioid dosing could be safely continued in postoperative patients for more effective pain management. [AHDB.2008;1(5):28-35.]
KEY POINTS

- Patient-controlled analgesia is widely used for postoperative opioid administration but is also associated with potentially fatal respiratory depression.
- Detecting a patient’s declining respiratory status before progression to respiratory depression is therefore essential.
- Postoperative patients typically are monitored by pulse oximetry, but increasing evidence supports the use of capnography for earlier and more reliable warnings of respiratory depression.
- In this study, capnography was more effective than pulse oximetry in providing early warning of respiratory depression. In all 9 cases, the capnography monitoring alarm was the impetus to assess these patients; the pulse oximetry monitor had not alarmed.

“PCA by proxy,” nurse-controlled analgesia in case the patient is not able to administer the drug without assistance, and close monitoring to detect early signs of respiratory depression.

A multidisciplinary team was responsible for upgrading the existing smart pump system (Alaris System with Guardrails suite of safety software; Cardinal Health, San Diego, CA; with Oridion Microstream capnography technology) by adding capnographic monitoring modules. The capnography modules were to be included on the same technology platform as PCA pumps. The team included members of the medical staff, nursing, pharmacy, respiratory therapy, biomedical engineering, information systems, and quality. Team members were responsible for reviewing information about the new technology, planning its implementation, and sharing decisions with their peers at all acute care hospitals, except for the hospital that had only recently become part of Main Line Health.

The team also developed educational materials to train staff on EtCO₂ technology. After implementation, the team met weekly to review any unresolved issues and track progress. Respiratory rate and EtCO₂ minimum and maximum levels were determined after speaking with representatives from other healthcare systems that had implemented this technology.

Methods

Capnography modules provided real-time data on ventilatory status of postoperative patients receiving PCA therapy by measuring respiratory rate, apneic events, and concentrations of EtCO₂. A nasal sampling cannula-like device was used to measure carbon
dioxide (CO₂) in exhaled breaths (Figure). Since any amount of CO₂ in an exhaled breath was indicative of gas exchange, respiratory rate data were assumed to be representative of the patient’s respiratory rate, as long as the sampling cannula was properly positioned. An alert was generated and a PCA “pause” protocol could automatically halt the opioid infusion if the respiratory rate was below the pre-established parameters (Table 1). A respiratory event was defined as occurring when the capnography monitor alerted the nurse (pulse oximetry did not alarm in any of the cases) to a change in respiration (apneic period or low respiratory rate) or to EtCO₂ levels outside the predetermined limits, paused the PCA infusion because of low respiratory rate, and prompted the nurse or physician to take immediate action. After a respiratory event, the incident was reviewed and the nurses were interviewed by a member of the quality department using a standard set of questions. Patient charts were also reviewed for details about the events, predisposing conditions of the patients, and any incidental findings for each case.

**Results**

In the first 5 months after implementing the capnography modules, a total of 634 patients received postoperative PCA therapy. Of these, 239 (38%) received hydromorphone and 297 (47%) received morphine. The remaining 98 (15%) were given fentanyl. The average age of the patients was 67.5 years, with the exception of 2 patients younger than age 50 years who were otherwise healthy.

Of the 634 patients receiving PCA therapy, 9 (1.4%) had respiratory depression that required intervention to avert further complications. Of the 9 patients with respiratory events, 6 (67%) patients were receiving hydromorphone; the other 3 (33%) patients were receiving morphine. All 9 patients were also receiving supplemental oxygen.

In 7 (78%) of the 9 patients who had respiratory events, the nursing assessment during the patient’s arrival from the postanesthesia care unit to the medical-surgical unit had caused concern about the patient’s condition. In 2 (22%) of these cases, the patients were otherwise stable on arrival to the unit.

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In 7 (78%) of the events, the patients were not receiving a PCA basal rate and the patients’ SpO₂ was more than 92%. One patient had an SpO₂ of 100% and 1 patient had an SpO₂ of 76% at the time that the capnographic monitors alarmed, suggesting a critical respiratory depression.

All respiratory depression events occurred within the first 24 hrs of initiating PCA therapy, with a mean time of 3.4 hrs, excluding an outlier with 23.5 hrs (Table 2). The median time from initiation of PCA therapy to the onset of respiratory events was 3.5 hrs.

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**Table 1** Capnography Alarm Limits for Postoperative Patients Using PCA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Established limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EtCO₂ high</td>
<td>50 mm Hg</td>
</tr>
<tr>
<td>EtCO₂ low</td>
<td>20 mm Hg</td>
</tr>
<tr>
<td>Respiratory rate high</td>
<td>38 bpm</td>
</tr>
<tr>
<td>Respiratory rate low</td>
<td>6 bpm</td>
</tr>
<tr>
<td>No breath alarm</td>
<td>20 seconds</td>
</tr>
</tbody>
</table>

PCA indicates patient-controlled analgesia; EtCO₂, end-tidal carbon dioxide; bpm, breaths per minute.
and the average time was 5.6 hrs. In addition, 1 patient had an event 23.5 hrs after starting PCA. When excluding this outlier patient, the average time to a respiratory depression event was 3.4 hrs.

In all cases, the capnography alarm was the impetus for the nurse to check on and assess these patients; the pulse oximetry monitor had not alarmed. On arrival in the patients’ rooms, the nurses found their patients to be unresponsive and took immediate action. In 4 (44%) of the 9 cases, the rapid response team was called to intervene, because of a dramatic change in the patient’s condition. In another 3 (33%), the attending physician or a resident was called to the bedside to intervene. In the remaining 2 (22%), the nurse stimulated the patient to breathe and continued to closely monitor the patient. In 4 (44%) of these patients, naloxone was administered to reverse the patient’s condition (Table 3). In the remaining cases, PCA was discontinued. These interventions resulted in positive outcomes for all the patients.

**Patient Cases**

The following case examples illustrate the advantages of using additional safety monitoring to allow for early detection of subclinical respiratory depression for all patients receiving PCA.

**Case 1.** PCA therapy was initiated in a 78-year-old man following surgical revision of a left total knee replacement. The patient also had a diagnosis of chronic obstructive pulmonary disease (COPD). He received hydromorphone with no basal rate and a PCA bolus dose of 0.2 mg with a 10-minute lock out. After using the PCA device for approximately 3 hrs, the patient’s nurse heard the capnography monitor alarming. On entering the room, the nurse found the patient unresponsive. The PCA had automatically paused, which meant that the patient’s respiratory had exceeded the predetermined lower limit of 6 bpm for more than 1 or 2 minutes. A rapid response team was called and 0.4 mg of naloxone was administered to the patient. The patient was awakened, saw many clinicians standing around his bed, and asked “What happened?”

**Case 2.** A 49-year-old woman was placed on PCA after an elective total abdominal hysterectomy and bilateral salpingo oopherectomy for menometrorrhagia. She had no other significant medical history. She received an initial bolus of 1 mg hydromorphone, followed by a basal rate of 0.2 mg/hr and a PCA bolus dose of 0.2 mg with a 10-minute lock out. Approximately 5 hrs after PCA therapy was initiated, a capnography monitor alarm brought the nurse to the bedside. The safety system had automatically paused the PCA infusion. The nurse assessment found the patient was unresponsive with a

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**Table 2** Postoperative Respiratory Events in 9 Patients Using PCA

<table>
<thead>
<tr>
<th>Patient age</th>
<th>Postoperative hrs to event</th>
<th>Rapid response team called?</th>
<th>Basal rate used?</th>
<th>Naloxone administered?</th>
</tr>
</thead>
<tbody>
<tr>
<td>82</td>
<td>2.5</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>78</td>
<td>3.0</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>78</td>
<td>2.5</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>74</td>
<td>3.5</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>73</td>
<td>6.25</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>70</td>
<td>3.5</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>64</td>
<td>2.5</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>49</td>
<td>3.5</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>40</td>
<td>23.5</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

PCA indicates patient-controlled analgesia.

**Table 3** PCA-related Respiratory Events: Composite Patient Data

<table>
<thead>
<tr>
<th>Variable</th>
<th>Patient data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (average)</td>
<td>67.5 yrs</td>
</tr>
<tr>
<td>Rapid response team called</td>
<td>4 of 9 (44.4%)</td>
</tr>
<tr>
<td>PCA included basal rate</td>
<td>2 of 9 (22.2%)</td>
</tr>
<tr>
<td>Naloxone given</td>
<td>4 of 9 (44.4%)</td>
</tr>
<tr>
<td>Postoperative time to event (mean)</td>
<td>3.4 hrs</td>
</tr>
</tbody>
</table>

PCA indicates patient-controlled analgesia.
respiratory rate of 6 bpm. A rapid response team was called and 0.2 mg of naloxone was administered. The patient responded, and PCA infusion was discontinued. The patient and her family requested that she remain on capnography monitoring overnight.

**Case 3.** A 64-year-old woman was placed on hydromorphone PCA after a sigmoid colectomy. Her medical history was significant for hypertension and diverticulitis, but without complications. PCA therapy included no basal rate. The PCA bolus dose was 0.3 mg, with a 10-minute lock out. Approximately 2.5 hrs after PCA was started, the capnography monitoring system alarmed because of a low respiratory rate and automatically paused the PCA infusion. The nurse assessed the patient, the attending physician was contacted, and the PCA was discontinued. Shortly after, the patient's respiratory rate returned to 14 bpm.

**Case 4.** A 78-year-old woman was placed on hydromorphone PCA therapy after inguinal repair. Her medical history was significant for hypertension and hypercholesterolemia. There was no basal rate of PCA, and the bolus rate was 0.5 mg, with a 10-minute lock out. Approximately 2 hrs after PCA therapy was initiated, the patient’s respiratory rate fell to 7 bpm, and the SpO₂ was 90% while receiving 5 L supplemental oxygen by nasal cannula. The nurse found the patient to be unresponsive. The PCA was discontinued and naloxone was administered. The patient’s respiratory rate and level of consciousness returned to baseline within 30 minutes, and her SpO₂ returned to 97% within an hour.

**Discussion**

The Joint Commission describes pain as the “fifth vital sign” that should be monitored with the same vigilance as blood pressure, pulse, temperature, and respiratory rate. Inadequate pain control is unethical, clinically unsound, and economically wasteful. Pain management experts have stated a pain level that is unacceptable to the patient is rated by the patient as a 4 or more on a 0-to-10-point pain scale and requires prompt intervention—obtaining an order for and administration of prescribed analgesic and nonpharmacologic modalities, as appropriate.

The implementation of capnography modules to monitor ventilatory response of patients receiving PCA therapy was an important part of hospital-wide efforts to enhance patient safety and quality of care in postoperative pain management. The American Society of Anesthesiologists emphasizes that ventilation and oxygenation are separate physiologic processes and that monitoring oxygenation by pulse oximetry is not a substitute for monitoring ventilatory function by capnography.

A growing body of evidence supports capnography's sensitivity in the detection of respiratory depression in patients receiving PCA therapy in general nursing care. Blinded capnography frequently identified respiratory depression undetected by the treating physicians. Another study found that a majority of patients with acute respiratory events had EtCO₂ abnormalities that occurred before oxygen desaturation or observed hypoventilation. During procedural sedation in children, capnography allowed early detection of arterial oxygen desaturation because of alveolar hypoventilation in the presence of supplemental oxygen.

The results of this case series provides additional evidence that pulse oximetry may fail to detect respiratory depression, particularly if a patient is receiving supplemental oxygen. In all 9 patients who experienced respiratory events, capnography monitors provided the only alert to declining respiratory function. Pulse oximetry did not alarm in any case. In 7 of the 9 cases, the SpO₂ was greater than 92%. In the detection of respiratory depression, monitoring respiratory rate and EtCO₂ concentration was more effective than monitoring oxygenation alone.

Results underscore the need for vigilance in postoperative care of patients receiving PCA, especially in the first 24 hrs. Another study found that 77.4% of patients suffered respiratory events in the first 24 hrs postoperatively. In our series, with excluding one outlier of 23.5 hours, all 9 patients experienced respiratory depression within the first 24 hrs with a mean time of 3.4 hrs.

Factors such as COPD, smoking, and obstructive sleep apnea can significantly increase the risk of respiratory events. In this case series, 89% of patients who had respiratory events had no history of respiratory disease. This supports the use of capnography to monitor all patients receiving PCA therapy, not only those recognized as being at high risk for opioid-induced respiratory depression.

In all 9 patients who experienced respiratory events, capnography monitors provided the only alert to declining respiratory function. Pulse oximetry did not alarm in any case.
Several studies have shown that a basal rate increases the total analgesic dose used and risk of respiratory depression. It is a common belief among clinicians that removing the basal infusion rate will potentially avoid the risks of respiratory depression. However, in our study, only 33% of the patients who required medical intervention were receiving a basal infusion rate. The occurrence of respiratory events in patients receiving no basal rate and having no evidence of PCA by proxy suggests that PCA by demand-bolus alone can deliver sufficient opioid to result in respiratory depression.

Hydromorphone is approximately 8 times more potent than morphine. The increased potency allows for better pain control but may increase the risk of respiratory events. In this case series, a much smaller percentage of the 634 patients receiving PCA therapy received hydromorphone than morphine (38% vs 47%), yet a greater percentage of respiratory events was related to hydromorphone than to morphine (67% vs 33%). Other studies have also shown an increased risk of respiratory events with hydromorphone compared with morphine.

Several studies have shown that a basal rate increases the total analgesic dose used and incidence of side effects such as respiratory depression. Many clinicians believe that removing the basal infusion rate will potentially avoid the risks of respiratory depression. However, in this case series, 78% of patients experiencing PCA-related respiratory depression had no basal rate.

Outcomes

Since October 2006, we had 9 patients whose level of sedation while receiving PCA opioids led to low respiratory rates. In each case, capnographic monitoring of respiratory rate alerted caregivers before pulse oximetry and prevented a serious adverse event. In most of the patients in this series, nursing assessment had already raised concerns about the patient’s condition. Capnographic monitoring provided real-time data that alerted nurses when immediate action was needed. All patients were properly treated without injury.

Concerns about potential respiratory depression also can prevent clinicians from treating pain adequately, which can adversely affect recovery and outcomes. The use of continuous capnography to monitor EtCO₂ and effective respiratory rate improves clinicians’ confidence that opioid doses can be safely increased to provide more effective pain management for all patients.

Other benefits of using capnography to monitor patients receiving PCA therapy include:
- Increased early nursing interventions to correct PCA-related respiratory distress
- Increased nursing confidence that patients were being effectively monitored for respiratory depression
- Effective use of the rapid response team to correct PCA-related respiratory distress and avoid increased costs of care that would otherwise follow respiratory arrest
- Measurable increases in patient safety during PCA therapy.

The use of continuous capnography to monitor EtCO₂ and effective respiratory rate improves clinicians’ confidence that opioid doses can be safely increased.

Conclusions

The cases in this series provide additional evidence that continuous capnographic monitoring offers more reliable and earlier indication of changes in patient respiratory status compared with continuous pulse oximetry, particularly in patients receiving supplemental oxygen administration. Hospital-defined alerts and data from the capnographic monitoring modules provided clinicians with the earliest warnings of respiratory distress. Automatic pausing of the PCA infusion by the capnography system and expeditious interventions by members of a multidisciplinary health care team helped prevent serious complications and the need for more intensive care. Without this PCA safety technology, patients might have needed additional interventions that could have negatively impacted their lives, increased their length of stay, increased the cost of their care, and utilized additional healthcare resources.

References

Stakeholder Perspective

Capnography in Procedural Anesthesia: At the Edge of a “Perfect Storm”

MEDICAL DIRECTORS: The case series in this article provides insight into the recognized utility of end-tidal carbon dioxide (EtCO₂) monitoring during procedural anesthesia in clinical settings at locations remote from the operating room, where sedation/analgesia is supervised by anesthesiologists who may not be continuously available to recognize hypoventilation by conventional clinical observations. Consistent with other studies of EtCO₂, respiratory depression was detected during patient-controlled analgesia (PCA) before changes in oxygenation were detected by pulse oximetry, permitting timely medical intervention. These clinical anecdotes thus resonate with mandates from the American Society of Anesthesiologists and the Joint Commission on Accreditation of Healthcare Organizations regarding the respiratory monitoring of patients undergoing anesthesia and lend credence to the position adopted by the Anesthesia Patient Safety Foundation.

However, consistent with the history of new technological innovations in medicine, reimbursement for capnography also can be contentious when indications for use and the environment for application extend outside of perioperative medical services. Emergency medical services and the
Capnography Monitoring in PCA

Stakeholder Perspective Continued

alternative care market, including physician offices, skilled nursing facilities, sleep centers, endoscopy centers, dental offices, and home healthcare services all provide venues in which EtCO₂ monitoring has been considered for a cornucopia of clinical conditions ranging from routine monitoring of ventilatory status—where the risk of respiratory failure can be high (eg, asthma, chronic obstructive pulmonary disease, coronary heart failure)—to biofeedback monitoring in anxiety disorders.

Aggressive marketing strategies emphasizing end-user benefits, creation of new markets by extending potential indications, and equipment replacement as a result of enhanced product capabilities accelerate entry of new technology into conditions and environments where enhanced clinical outcomes are not as well established, and where reimbursement is therefore inconsistent.

The use of a case series to illustrate the medical importance of EtCO₂ in PCA thus occurs within a hierarchy of evidentiary standards in clinical research. Case reports, case series, database analyses, observational studies, controlled clinical trials, and replicated controlled clinical trials represent paradigms of increasing complexity and persuasiveness that collectively provide compelling arguments to support the utilization of a novel technology. Although medical device clinical trials represent approximately 1% of total research expenditures within the pharmaceutical/medical device industry, prospective studies examining the utility of new technology, such as capnography, in enhancing clinical outcomes become imperative to shape the impact of an otherwise “perfect storm” in the healthcare community—novel, relatively inexpensive technology; apparently self-evident utility; and diverse clinical applications.

Michael F. Murphy, MD, PhD
Worldwide Clinical Trials
Chadds Ford, PA

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