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Capnography and Respiratory Depression

Is capnography a good way to monitor at-risk postsurgical patients? A prospective trial examines the question.

Overview: In order to determine whether opioid-naive patients at risk for respiratory depression are better monitored with either capnography or pulse oximetry and respiratory-rate assessment, the authors conducted a randomized, prospective trial. In 54 opioid-naive postoperative orthopedic patients at one hospital, capnography resulted in greater detection of respiratory depression, and the authors conclude that capnography may be more appropriate for use with postsurgical high-risk patients taking opioids on the general care nursing unit. Capnography's sensitivity in the detection of pauses in breathing in the sedated patient may have the added advantage of indicating those patients who may be at risk for obstructive sleep apnea. Further research is needed to confirm these results.

Respiratory depression is an adverse event usually associated with high opioid doses in opioid-naive patients—those who have not been taking opioids regularly—but it may also occur with normal opioid doses. A literature review by Smith found no consistent statistics on the prevalence of opioid-related adverse events in postsurgical patients, with figures ranging downward from 1.2% to one-tenth that amount.[1]

Obstructive sleep apnea (OSA), in which the upper airway may, at intervals, become partly or completely occluded during sleep, also places hospitalized patients at higher risk for respiratory complications because opioids can relax pharyngeal tone and increase the airway occlusion already found in people with OSA.[2,3] Epidemiologic data from a decade ago indicated a prevalence of undiagnosed OSA of up to 5% in Western countries,[4] but because the rate of obesity, a major risk factor for OSA, has increased since that time, the prevalence of OSA may now be even higher than 5%. Many people with OSA have never been diagnosed with the condition. In one study of patients undergoing hip or knee replacement surgery, 35.6% of 101 patients with OSA were not diagnosed with the condition until after their surgery, and one-third of them "suffered a substantial respiratory or cardiac complication."[2]

Regardless of whether OSA is present, any postsurgical patient receiving opioids for pain should be routinely assessed for changes to the sedation level and respiration. This is usually done by direct observation of the sedation level and the depth, regularity, and rate of respirations (see "Monitoring Sedation," *Pain Control*, February 2002). Pulse oximetry is sometimes used in addition to assess respiratory status.

A pulse oximeter measures the percentage of the patient's hemoglobin that is saturated with oxygen; it consists of a monitor and sensor attached to the patient's finger. But results of pulse oximetry may be deceptive, especially when the patient is receiving supplemental oxygen, because pulse oximetry may detect a high enough level of arterial oxygen saturation even when the respiration is depressed.[5,6] Pulse oximetry does not detect changes in respiration rate, pauses in breathing, or exhaled carbon dioxide (CO_2) levels, important early indicators of respiratory depression, and declining ventilation in patients on supplemental oxygen may not be recognized until bradypnea progresses to apnea, which can lead to harm or even death.[7]

In *capnography,* a nasal cannula delivers supplemental oxygen *and* measures respiration, including exhaled CO_2 (also known as end-tidal CO_2), apneic events (measured by a set threshold level, such as any pause in breathing longer than 20 seconds), and respiratory rate (measured in breaths per minute). Placing the capnography module on the patient's face is similar to initiating a nasal cannula for supplemental oxygen. Breath samples are obtained through both nos-

Alarm Settings for the Alaris $EtCO_2$ Capnography Module*

- End-tidal carbon dioxide: 60 mmHg (high), 0 mmHg (low)
- Respiratory rate: 40 breaths per minute (high), 6 breaths per minute (low)
- Apnea (no breathing): 20 seconds

* All settings were established by the author; this is the first reported randomized, prospective, controlled study of the use of capnography on general care units.

Parenteral Morphine Equivalents*

Hydromorphone IV 1.5 mg
Fentanyl IV 0.1 mg
Hydrocodone PO 10 mg
Oxycodone PO 20 mg
Meperidine IV 100 mg

* All doses above are equivalent to morphine IV 10 mg. On the day of surgery, the amount of parenteral morphine equivalent includes doses on the postanesthesia care unit and on the medical–surgical unit. Doses are based on single dose studies and given over a 4-hour period.

Ashburn MA, Lipman AG. *Principles of Analgesia Use in the Treatment of Acute Pain and Cancer Pain*. 5th ed. Glenview, IL: American Pain Society. 2003.

trils, and oxygen is delivered through small pin holes. The extension in front of the mouth can be used to obtain readings if the patient breathes through the mouth instead of the nose. Performing capnography typically requires about 15 minutes of initial staff education.

For many years, capnography was used primarily during surgery; more recently, monitors have become more portable and practical for use on the general care nursing unit. Emergency medical technicians are also beginning to use it more often. But use of capnography outside the operating room is new and not indicated for every patient. One determining factor is cost: is the cost of purchasing, using, and maintaining a small number of devices balanced against the cost of adverse events?

Because most patients tolerate opioid analgesics without serious adverse events on the general care nursing unit, studies of new technologies such as capnography should focus on patients at high risk for opioid-induced respiratory depression. We performed a randomized, prospective trial of patients who've had orthopedic surgery and are receiving opioids and are at risk for OSA, in order to determine whether capnography alone is more sensitive than pulse oximetry with respiration rate assessment by observation or auscultation to detect respiratory depression.

METHODS

Outcomes measured. The primary outcome measured was respiratory depression: an episode was defined as a respiratory rate of six breaths per minute or fewer, an apneic event lasting longer than 20 seconds, an end-tidal CO_2 level greater than 60 mmHg, or oxygen saturation less than 88%. (The first two of these could be measured in both groups; of the latter two, end-tidal CO_2 level greater than 60 mmHg could be measured only in the capnography group and oxygen saturation only in the control group.)

A secondary outcome measured was pauses in breathing during sleep, one of the risk factors for moderate-to-severe OSA that's listed in the 2006 American Society of Anesthesiologists Practice Guidelines for the Perioperative Management of Patients with Obstructive Sleep Apnea.[8] Other outcomes measured were time in the postanesthesia care unit (PACU), distance ambulated on the first postoperative day (as recorded by a physical therapist), and morphine equivalent consumed (as recorded for the 36 hours and converted by a pharmacist to standard parenteral morphine equivalence, using the criteria listed in *Parenteral Morphine Equivalents,* at left). The patients' pain intensity (as measured on a 0-to-10 pain-rating scale) was collected during the three postoperative time periods: in the PACU, the remainder of the first 24 hours after surgery spent on the general care nursing unit, and the first full day after surgery.

Randomization. After institutional review board approval from Presbyterian Hospital of Dallas, 54 opioid-naive patients who were consecutively admitted between October 2006 and January 2007 for orthopedic surgery and who met inclusion criteria were enrolled in the study and randomized in the PACU to the capnography group (n = 29)

or the control group (n = 25). Inclusion criteria, some of which were determined from research literature,[2, 3, 8, 9] were as follows: all patients had to have a physician's order for opioid analgesia and be older than 18 years of age; in addition, patients had to be breathing spontaneously (nonventilated), be without a diagnosis of OSA, not be using a continuous positive airway pressure (CPAP) device, and be able to report pain intensity on a 0-to-10 pain rating scale. Patients also had to have *at least one* of the following:

- a body mass index of 30 or more
- a history of snoring
- a history in the PACU of one episode of a respiratory rate of less than 10 breaths per minute
- a basal (continuous) dosage of IV opioid or continuous-release oral opioid

The control group was monitored every four hours by spot-check pulse oximetry and respiration rate assessment by observation or auscultation; the capnography group was monitored by capnography alone.

Equipment. We used the Alaris $EtCO_2$ module (manufactured by Cardinal Health), which employs a Microstream Smart CapnoLine capnography nasal cannula by Oridion. (For specification of settings, see *Alarm Settings,* page 36.) A nasal cannula was applied to each patient in the PACU after randomization (in the capnography group, a CapnoLine cannula able to deliver supplemental oxygen and measure end-tidal CO_2; in the control group, a standard oxygen cannula), and patients were moved to the general care nursing unit within one hour of enrollment.

Outcomes were measured and documented in the PACU and then on the general care nursing unit for 36 hours by the clinicians caring for the patients.

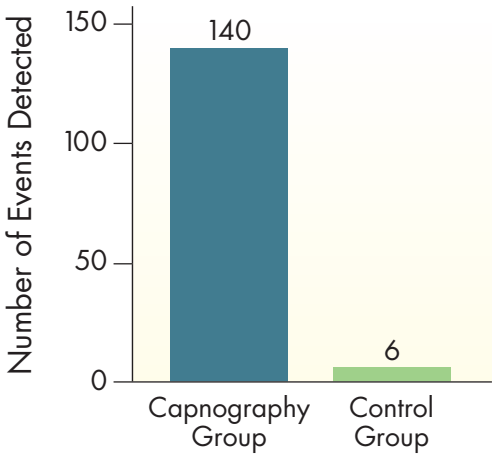
RESULTS

With regard to demographic characteristics (sex, age, body mass index, opioid allergy, type of orthopedic procedure, and length of stay), there were no statistically significant differences between the two groups (see Table 1, page 38).

Respiratory depression was detected at a significantly higher rate in the capnography group (t test = 2.1117; $P = 0.03$). In total, 146 episodes of respiratory depression were detected during the 36 hours on the general care nursing unit: 140 in the capnography group and six in the control group (as shown in Figure 1, at right). All of these episodes were detected because the patient either took six or fewer breaths per minute or had an episode of apnea lasting longer than 20 seconds. Seventeen patients (15 in the capnography group and two in the control group) accounted for all episodes of respiratory depression. Pauses in breathing while sleeping, an indicator of OSA risk, were detected in the capnography group at twice the rate as in the control group (48% and 24%, respectively).

The other two indicators of respiratory depression in this study (an end-tidal CO_2 level of greater than 60 mmHg and oxygen saturation of less than 88%) did not contribute to the outcomes measured, suggesting that they may be less sensitive indicators of changes in respiratory function. In all cases, the need to adjust drug dose or administration route was recognized early enough that naloxone (Narcan) was not needed to reverse opioid-induced respiratory depression. There were no deaths in either group.

Figure 1. Number of Episodes of Respiratory Depression Detected



According to the study parameters, an episode of respiratory depression was defined as a respiratory rate of six breaths per minute or fewer, an apneic event lasting longer than 20 seconds, an end-tidal carbon dioxide level greater than 60 mmHg, or oxygen saturation less than 88%. In practice, however, all episodes detected were in one of the first two categories. The results were statistically significant ($P = 0.03$).

Of the last four enrollment criteria listed above (one of which had to be present), only a respiratory rate of less than 10 breaths per minute while in the PACU was a strong predictive indicator of a subsequent respiratory event on the general care nursing unit, as measured by a Cochran–Mantel–Haenszel correlation test (13.26; $P = 0.0003$). This finding suggests that patients who have such an event in the PACU may be strong candidates for capnographic monitoring on the general care nursing unit.

The two groups had no statistically significant differences in opioid use on the day of surgery or on the first postoperative day

Table 1. Demographic Characteristics of Study Subjects (N = 54)

Characteristic	Control (n = 25)	Capnography (n = 29)
	Mean (SD)	
Age, in years	63.5 (10.7)	67.6 (9.9)
Body mass index	34.5 (6.6)	34.2 (5.2)
Length of stay, in days	3.8 (1.4)	3.9 (1.5)
	Percentage (n)*	
Female sex	60% (15)	76% (22)
Opioid allergy	36% (9)	24% (7)
Total knee replacement (TKR)	56% (14)	59% (17)
Bilateral TKR	8% (2)	17% (5)
TKR with bone biopsy	8% (2)	4% (1)
Hip replacement	20% (5)	21% (6)
Shoulder repair	8% (2)	0% (0)

* Percentages do not sum to 100 because of rounding and because patients could be represented in more than one category.

Table 2. Opioid Use (N = 54)*

Characteristic	Control (n = 25)	Capnography (n = 29)
	Mean (SD)	
Dose PME, day of surgery	41.9 mg (27.3)	33.9 (17.8)
Dose PME, postoperative day 1	28.1 mg (21)	26.9 (21)
	Percentage (n)*	
Basal opioid dose	16% (4)	24% (7)
PCA opioid	60% (15)	65% (19)
Intermittent opioid	40% (10)	34% (10)

* PME = parenteral morphine equivalent; PCA = patient-controlled analgesia. Differences were not statistically significant. Percentages do not sum to 100 because of rounding and because patients could receive both a basal dose and PCA.

(see Table 2, at left) or in pain scores, when measured in the PACU and on the day of and the day after surgery in the general care nursing unit (see Table 3, page 39).

Those in the capnography group required more total time in the PACU than those in the control group (2.9 hours versus 2.1 hours, respectively; $t = 2.3879$; $P = 0.03$), and the patients in the capnography group ambulated only about a third as far as those in the control group on the first postoperative day (a mean of 55.8 feet, versus 159.5 feet in the control group), although that difference wasn't statistically significant.

DISCUSSION: IMPLICATIONS FOR NURSES

The findings of this study are similar to those of Miner and colleagues, who looked at the effectiveness of capnography in detecting "subclinical" respiratory depression, although during procedural sedation rather than during the postoperative period.[10] Our study also shows that when both supplemental oxygen and opioids are used in the immediate postoperative period, capnography may help in identifying pauses in breathing during sleep, one of the risk factors for OSA.

Capnography has its limitations. It should be used only in patients receiving supplemental oxygen; pulse oximetry alone is a good indicator of respiratory decline in a patient who is breathing room air. The use of capnography in patients with diagnosed OSA who wear a CPAP device needs further study because it's not clear whether accurate readings of end-tidal CO_2 can be obtained when a CPAP device is used at the same time. As with most types of

Table 3. Mean Pain Scores (N = 54)*

Unit	Control (n = 25)	Capnography (n = 29)
	Mean (SD)	
Postanesthesia care unit	5.1 (3.4)	4.7 (3.1)
Nursing unit—day of surgery	3.1 (2.5)	2.5 (2.1)
Nursing unit—day after surgery	4.2 (5)	2.7 (1.7)

* Percentages do not sum to 100 because of rounding and because patients could be represented in more than one category.

monitoring on the general care nursing unit, capnography may require more staff time to implement, and the cannula may impede activities of daily living, such as eating; it's therefore not recommended for every postoperative patient receiving opioids. Also, this study found that patients in the capnography group walked a shorter distance than did those in the control group, which suggests that capnography may be a hindrance to ambulation. The cannula can be removed when a patient is walking with the help of a physical therapist or nurse, since the risk of respiratory arrest at that time is minimal.

Providers' satisfaction. Nurses, surgeons, and respiratory therapists on the general care nursing unit were surveyed informally after using capnography (nurses and other clinicians in the PACU were not surveyed). Asked whether they thought capnography was helpful for assessing respiratory function on the general care nursing unit, many clinicians indicated that it was. Several night-shift nurses said that capnography was useful for assessing respiratory status during night-time sleep.

Patients' and families' satisfaction. Patient and family education is very important when using capnography. There were two cases in the capnography group in which the patient or family member initially complained about the alarm sounding when a respiratory event occurred. When it was explained that the alarm indicated an adverse respiratory event—either an episode of apnea lasting 20 seconds or longer or a respiratory rate of six or fewer breaths per minute—they expressed acceptance of the use of capnography.

Balancing the need for opioid analgesia against the risk of adverse events requires painstaking assessment, of which monitoring sedation level has long been an essential component. This study's findings suggest that capnography may help identify early changes in respiratory function better than pulse oximetry and respiratory rate assessment by observation or auscultation. Further research is needed to determine the role of electronic monitoring in the prevention of clinically significant opioid-induced respiratory depression. ▼

Rob Hutchison is a clinical specialist in pain management and palliative care at Presbyterian Hospital of Dallas. Les Rodriguez is a clinical education specialist at Harris Methodist Southwest Hospital, Fort Worth, TX. *The devices used in this study were supplied by Cardinal Health and were returned after their use; Hutchison also received an honorarium from Cardinal Health to speak at the 2007 convention of the American Society of Pain Management Nurses. Cardinal Health did not review the content of this article or in any way influence the study results.* *Contact author, Rob Hutchison: robhutchison@texashealth.org.* Pain Control *is coordinated by Chris Pasero, MS, RN, FAAN: cpasero@aol.com.*

REFERENCES

1. Smith LH. Opioid safety: is your patient at risk for respiratory depression? *Clin J Oncol Nurs* 2007;11(2):293-6.
2. Gupta RM, et al. Postoperative complications in patients with obstructive sleep apnea syndrome undergoing hip or knee replacement: a case-control study. *Mayo Clin Proc* 2001;76(9):897-905.
3. Boushra NN. Anaesthetic management of patients with sleep apnoea syndrome. *Can J Anaesth* 1996;43(6):599-616.
4. Young T, et al. Epidemiology of obstructive sleep apnea: a population health perspective. *Am J Respir Crit Care Med* 2002;165(9):1217-39.
5. Maddox RR, et al. Clinical experience with patient-controlled analgesia using continuous respiratory monitoring and a smart infusion system. *Am J Health Syst Pharm* 2006;63(2):157-64.
6. Fu ES, et al. Supplemental oxygen impairs detection of hypoventilation by pulse oximetry. *Chest* 2004;126(5):1552-8.
7. Ayas N, et al. Unrecognized severe postoperative hypercapnia: a case of apneic oxygenation. *Mayo Clin Proc* 1998;73(1):51-4.
8. Gross JB, et al. Practice guidelines for the perioperative management of patients with obstructive sleep apnea: a report by the American Society of Anesthesiologists Task Force on Perioperative Management of Patients with Obstructive Sleep Apnea. *Anesthesiology* 2006;104(5):1081-93.
9. National Center for Health Statistics. *Prevalence of overweight and obesity among adults: United States, 2003–2004*. Centers for Disease Control and Prevention. 2007. http://www.cdc.gov/nchs/products/pubs/pubd/hestats/overweight/overwght_adult_03.htm.
10. Miner JR, et al. End-tidal carbon dioxide monitoring during procedural sedation. *Acad Emerg Med* 2002;9(4):275-80.