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Does End-tidal Carbon Dioxide Monitoring Detect Respiratory Events Prior to Current Sedation Monitoring Practices?

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Abstract

Objectives: The value of ventilation monitoring with end-tidal carbon dioxide (ETCO₂) to anticipate acute respiratory events during emergency department (ED) procedural sedation and analgesia (PSA) is unclear. The authors sought to determine if ETCO₂ monitoring would reveal findings indicating an acute respiratory event earlier than indicated by current monitoring practices.

Methods: The study included a prospective convenience sample of ED patients undergoing PSA. Clinicians performed ED PSA procedures with generally accepted patient monitoring, including oxygen saturation (SpO₂), and clinical ventilation assessment. A study investigator recorded ETCO₂ levels and respiratory events during each PSA procedure, with clinical providers blinded to ETCO₂ levels. Acute respiratory events were defined as SpO₂ ≤ 92%, increases in the amount of supplemental oxygen provided, use of bag-valve mask or oral/nasal airway for ventilatory assistance, repositioning or airway alignment maneuvers, and use of physical or verbal means to stimulate patients with depressed ventilation or apnea, and reversal agent administration.

Results: Enrollment was stopped after independent review of 20 acute respiratory events in 60 patient sedation encounters (33%). Abnormal ETCO₂ findings were documented in 36 patients (60%). Seventeen patients (85%) with acute respiratory events demonstrated ETCO₂ findings indicative of hypoventilation or apnea during PSA. Abnormal ETCO₂ findings were documented before changes in SpO₂ or clinically observed hypoventilation in 14 patients (70%) with acute respiratory events.

Conclusions: Abnormal ETCO₂ findings were observed with many acute respiratory events. A majority of patients with acute respiratory events had ETCO₂ abnormalities that occurred before oxygen desaturation or observed hypoventilation.

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Procedural sedation and analgesia (PSA) is an integral part of emergency medicine practice. Current emergency department (ED) practice guidelines

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Presented at the SAEM annual meeting, Orlando, FL, May 2004. Medtronic Emergency Response Systems (Redmond, WA) lent two LIFEPAK 12 defibrillator/monitor series with accompanying accessories to allow for simultaneous monitoring and recording of end-tidal carbon dioxide and oxygen saturation data.

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advocate routine assessment of patients during moderate or deep sedation with continuous oxygenation and hemodynamic monitoring.¹ A variety of patient assessment scales are also used, including the Ramsay scale and the modified postanesthesia recovery score. Ventilation monitoring by clinical observation is also routine during PSA; however, recent studies have questioned the sensitivity of this practice for early changes in respiratory status.^{2,3}

In the operating room, end-tidal carbon dioxide (ETCO₂) monitoring is standard practice for ventilation monitoring and is the earliest indicator of airway compromise, including respiratory depression, apnea, and upper airway obstruction. In the setting of ED PSA, the utility of ETCO₂ monitoring is less clear, and no specialty organizations have advocated its routine use as an essential element for ED PSA practice.^{1,4–10}

The primary goal of this study was to determine the ability of ETCO₂ monitoring during PSA to detect

acute respiratory events before detection by current monitoring methods. We sought to assess the frequency of abnormal ETCO₂ findings during PSA and to define the relationship between observed ETCO₂ findings and acute respiratory events.

METHODS

Study Design

This investigation was a prospective observational case series with a convenience sample of ED patients undergoing PSA. The study was approved by the institutional review board for research on human subjects. Prospective informed consent was obtained.

Study Setting and Population

The study site is a 500-bed tertiary care hospital with an ED volume of 52,000 patients per year and approximately 250 PSA interventions per year. Emergency attending or resident physician personnel considered consecutive adult and pediatric ED patients for study enrollment at the time of the decision to perform PSA. Enrollment was conducted over a six-month period (May to October 2004). Patients were excluded from enrollment if unable to give informed consent or if there were no study investigators available.

Study Protocol

Procedural sedation and analgesia was performed in a fashion consistent with generally accepted guidelines, including monitoring continuous oxygen saturation (SpO₂), heart rate, cardiac rhythm, respiratory rate, and interval blood pressure.¹

A study investigator who did not participate in patient care was present throughout each PSA encounter and recorded all study data and observations, assured the quality of SpO₂ and ETCO₂ waveform data, and assured the proper positioning of patient monitoring equipment. The study investigators were four emergency physicians, one attending physician and three resident physicians, who enrolled patients during ED clinical shifts. These investigators agreed on monitoring practices and procedures before beginning patient enrollment and intermittently met to assure that consistent enrollment practices were being maintained. The clinical team was blinded to study monitoring data, including ETCO₂ findings, throughout the PSA period.

Outcome Measures

Study measurements included a Ramsay score clinical assessment and patient monitoring data (SpO₂, heart rate, respiratory rate, and ETCO₂) obtained via a multiparameter monitor (LIFEPAK 12 defibrillator/monitor series; Medtronic Emergency Response Systems, Redmond, WA). ETCO₂ monitoring was performed using a combined oral/nasal cannula for ETCO₂ measurement that simultaneously samples CO₂ and delivers low-flow oxygen. Administration of supplemental oxygen (2 L/min) during PSA was routine practice during the study period and a component of the institutional PSA policy.

The LIFEPAK 12 series Microstream technology quantitatively assesses expired CO₂ directly via an infrared light beam with a narrow wavelength of light that is pro-

jected through the exhaled gas sample. The intensity of the transmitted light is measured, with the light absorbed dependent on the concentration of CO₂ molecules in the sample.

The ETCO₂ data displayed to the study investigator included a continuous graphical display of the detected exhaled CO₂ waveform (capnography) and a continuous numerical display of measured CO₂ (capnometry). Recorded study monitoring data included a time and date signature for the data assessment, capnometric ETCO₂ value, respiratory rate, and SpO₂. The LIFEPAK 12 software was not configured to record capnography waveform data. Study monitoring data were recorded every 30 seconds during PSA and were collected simultaneously with the clinical team monitoring. In addition to the 30-second interval monitoring data, data were captured at the following times: baseline observations before medication administration, administration of any medication (either sedative or analgesic), observed acute respiratory events, acute clinical interventions for respiratory events, and return to baseline.

We defined clinically important acute respiratory events and related clinical interventions to include one or more of the following: SpO₂ ≤ 92%; increases in the amount of supplemental oxygen provided in response to observed apnea, hypoventilation, or desaturation (e.g., increasing oxygen from 2 to 4 L or from low-flow cannula to high-flow facemask); use of bag-valve mask or oral/nasal airway for ventilatory assistance or apnea; repositioning or airway alignment maneuvers for ventilation or apnea; physical or verbal stimulation for depressed ventilation or apnea; and reversal agent administration. A change in ETCO₂ level ≥ 10 mm Hg from the pre-sedation baseline and an intrasession ETCO₂ level ≤ 30 mm Hg or ≥ 50 mm Hg were considered investigational acute respiratory events.^{4,6-9} For observed acute respiratory events, the type and time of the acute respiratory events were entered into the monitor along with the clinical assessment and vital sign data at that time.

Data Analysis

Patient enrollment was planned for a one-year period of PSA encounters with a projected volume of 250 patients. The investigators anticipated an acute respiratory event occurrence rate of 15% based on a PSA database at this institution and the acute respiratory event definition used for the study protocol.

In response to concerns raised by the emergency physician faculty and the institutional review board for research on human subjects at the study site concerning the uncertain implication of PSA ETCO₂ findings, the investigators were required to institute an interim safety analysis for each 30-patient enrollment block. This analysis was performed by two study investigators and a research nurse who did not participate in the study. The institutional review board and physician staff identified a blinded study cessation point as investigative findings suggestive of periods of patient apnea or hypoventilation undetected by standard monitoring practices yet revealed with ETCO₂ continuous assessment.

Measurements are reported using descriptive statistics. Selected continuous variables are reported as

median values with range. The software package used for data collection and analysis was SPSS 11.0 (SPSS Inc., Chicago, IL).

RESULTS

After review of two 30-patient enrollment blocks, it was determined that further use of ET_{CO}₂ monitoring should proceed in a nonblinded fashion and the study was terminated. Fifty-nine patients with 60 PSA encounters were enrolled over the six-month period. One patient had two separate PSA encounters during a single ED visit (midazolam and fentanyl for transesophageal echocardiography, followed approximately one hour later with propofol for atrial fibrillation cardioversion). Patient demographic and clinical descriptors are shown in Table 1.

ET_{CO}₂ Findings

Abnormal ET_{CO}₂ findings were documented in 36 of the 60 encounters (60%). For those patients with abnormal ET_{CO}₂ levels, 32 patients had abnormally low levels and five patients had abnormally high levels (one patient had both a low and a high level during the PSA encounter). In 16 (44%) of these 36 encounters, there were no other acute respiratory events observed and no interventions by the clinical team. These abnormal ET_{CO}₂ levels ranged from single, isolated abnormal ET_{CO}₂ recordings to periods of multiple, prolonged abnormal ET_{CO}₂ values for each patient.

Acute Respiratory Events

Investigators documented 20 acute respiratory events in the 60 PSA encounters (33%). A description of these patients and their acute respiratory events are displayed in Table 2. An illustrative case of a patient with an acute res-

piratory event and associated monitoring data is shown in Figure 1.

Seventeen patients (85%) with acute respiratory events demonstrated ET_{CO}₂ findings indicative of hypoventilation or apnea. These abnormal ET_{CO}₂ findings were documented before changes in SpO₂ or observed changes in respiratory rate in 14 patients (70%) with acute respiratory events. All adverse respiratory events resolved with the interventions documented in Table 2.

DISCUSSION

Respiratory depression and airway obstruction have been cited as the primary cause of adverse events associated with PSA.¹⁰ Current assessment of these parameters is by clinical observation, continuous pulse oximetry, and observed respiratory rate.

Clinical observation of the patient is known to be limited in its ability to detect respiratory depression and obstruction during PSA.^{4,10} Continuous pulse oximetry is also limited for detection of respiratory depression and obstruction, given the physiologic differences between oxygenation and ventilation. The practice of preoxygenation, via supplemental oxygen before and during PSA, may further delay the detection of airway compromise with pulse oximetry.^{4,11} Given these limitations, a direct assessment of ventilatory status would offer an enhancement over clinical assessment and pulse oximetry.

Currently, the only direct assessment of patient ventilation advocated in PSA practice guidelines is the health care provider's subjective observation of ventilation rate and depth.^{1,10} Our findings suggest the limited utility of this subjective ventilatory assessment, because abnormal ET_{CO}₂ findings were common during many of the PSA encounters. This observation has been previously reported in similar settings.^{4,6-9}

End-tidal carbon dioxide monitoring has been shown to be the earliest indicator of airway compromise.^{7,12-15} Our study attempted to investigate the quantitative temporal relationship between SpO₂ and ET_{CO}₂ monitoring in the detection of PSA-related acute respiratory events. Changes in ET_{CO}₂ values in response to patient hypoventilation or apnea occurred in the majority of patients before changes in SpO₂. In cases where acute respiratory events were observed and acted on by the clinical team, blinded abnormal ET_{CO}₂ findings were often present at the time of or up to four minutes before clinical recognition.

Our results support a recent editorial advocating the use of routine ET_{CO}₂ monitoring for deep sedation.¹⁶ ET_{CO}₂ monitoring has not been widely adopted for ED PSA due to the lack of data demonstrating its ability to increase detection of acute respiratory events.¹

Previous investigations have demonstrated transient hypercapnia associated with brief periods of hypoventilation requiring no interventions.¹ In contrast, we observed reduction or absence of ET_{CO}₂ in most cases where an abnormal ET_{CO}₂ finding was recorded. We believe this observation is an accurate representation of ET_{CO}₂ findings in patients with hypoventilation or apnea. No hyperventilation of patients was noted clinically during the investigation, and hyperventilation was not

Table 1
Baseline Characteristics for 59 Patients with 60 PSA Encounters; Procedures and PSA Medications Are Correlated with 20 Acute Respiratory Events

Characteristic	No. (%)	No. of Patients With Acute Respiratory Event (N = 20)
Median (range) age (yr)	38 (1-89)	
Male (%)	35 (58)	
Procedure (%)		
Dislocation reduction, shoulder	10 (16)	3
Dislocation reduction, hip	7 (12)	5
Fracture reduction	18 (30)	4
Cardioversion	11 (18)	7
Wound closure	10 (16)	1
Transesophageal echocardiography	1 (2)	0
Tube thoracostomy	1 (2)	0
Disimpaction	1 (2)	0
Foreign body removal	1 (2)	0
PSA medication (%)		
Propofol	41 (68)	18
Etomidate	4 (7)	1
Midazolam	3 (5)	0
Ketamine	12 (20)	1

PSA = procedural sedation and analgesia.

Table 2
ETCO₂ Findings for Patients with an Acute Respiratory Event

Patient Age (y)/Gender	Acute Respiratory Event(s)	Abnormal ETCO ₂ ?*	ETCO ₂ Finding	Relationship of Abnormal ETCO ₂ to Event (seconds)
38/M	Desat, Stim	No	N/A	N/A
60/F	Desat, Stim	No	N/A	N/A
68/F	Desat, +O ₂ , Stim	No	N/A	N/A
68/M	Desat, Repos, Stim	Yes	Low ETCO ₂	-271
89/F	Desat, +O ₂ , Repos, Stim	Yes	Low ETCO ₂	-178
87/F	Desat, Stim	Yes	Low ETCO ₂	-170
17/F	Apnea, +O ₂ , Stim	Yes	Low ETCO ₂	-149
65/M	Desat, +O ₂ , Stim	Yes	Low ETCO ₂	-146
81/F	Desat, +O ₂ , Repos, Stim	Yes	Low ETCO ₂	-104
68/M	Desat, +O ₂ , Stim	Yes	Low ETCO ₂	-94
40/F	Desat, Repos, Stim	Yes	Low ETCO ₂	-88
38/M	Desat, +O ₂ , Repos, Stim	Yes	Low ETCO ₂	-79
57/M	Desat, +O ₂ , Repos, Stim, BVM	Yes	Low ETCO ₂	-57
73/F	Desat, Stim	Yes	Low ETCO ₂	-41
59/F	Desat, +O ₂ , Repos, Stim, BVM	Yes	Low ETCO ₂	-34
73/M	Desat, +O ₂ , Stim	Yes	Low ETCO ₂	-24
73/M	Desat, +O ₂ , Stim	Yes	Low ETCO ₂	-12
68/M	Desat, +O ₂ , Stim	Yes	Low ETCO ₂	0
63/F	Desat, +O ₂ , Repos, Stim, BVM	Yes	Low ETCO ₂	0
41/M	Desat, + O ₂ , Repos, Stim, BVM	Yes	High ETCO ₂	0

ETCO₂ = end-tidal carbon dioxide; Desat = oxygen saturation ≤92%; Stim = physical or verbal stimulus to patient for purposes of stimulating ventilation; N/A = not applicable; +O₂ = increased oxygen during PSA; Repos = reposition of patient for purposes of improving ventilation; BVM = use of bag-valve mask for ventilation.
 Minus sign denotes an abnormal ETCO₂ finding occurring before the acute respiratory event; 0 denotes an abnormal ETCO₂ finding occurring simultaneously with the acute respiratory event.
 * Abnormal ETCO₂ defined as change from baseline ETCO₂ level ≥ 10 mm Hg or ETCO₂ level ≤30 or ≥50 mm Hg.

shown in study respiratory rate data to account for the observed low ETCO₂ values during PSA.

A balance must exist between a monitoring modality that detects clinically relevant data contributing to patient safety and a monitoring modality that captures “abnormal findings” of questionable value to the clinical encounter. While the clinical observation and routine monitoring of patients with respiratory events in this investigation were often preceded by abnormal ETCO₂

findings, many abnormal ETCO₂ events were isolated or transient and not associated with a subsequent clinically meaningful event requiring intervention by the clinical team. Additionally, the impact of earlier detection of hypoventilation and/or apnea with ETCO₂ data does not necessarily translate into the potential to effect a clinical intervention that would have altered the recorded respiratory event. Future studies are needed to investigate the impact of routine ETCO₂ monitoring on reduction of

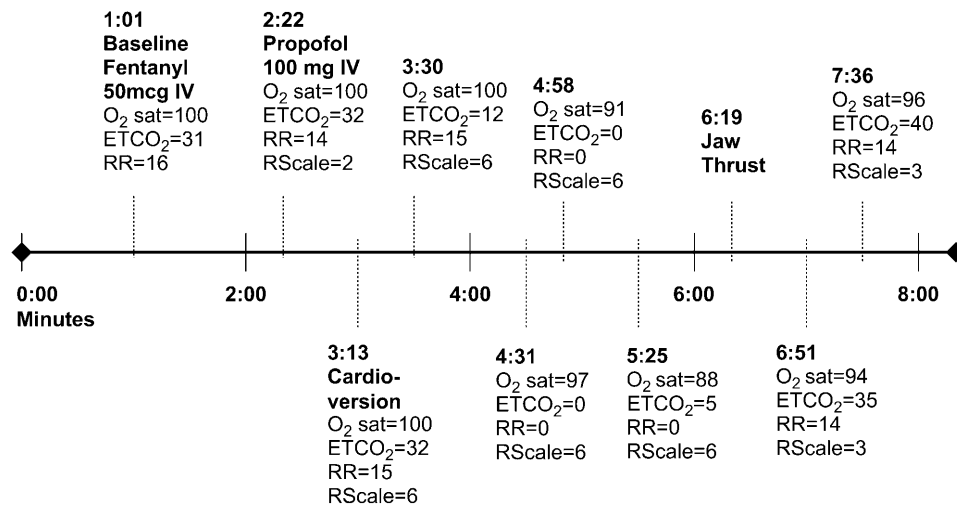


Figure 1. A 40-year-old woman undergoing PSA for electrical cardioversion of atrial fibrillation. ETCO₂ = End tidal carbon dioxide; SpO₂ = hemoglobin-oxygen saturation; RR = airway respiratory rate as documented by capnography; RScale = Ramsay sedation scale (range, 1 to 6).

patient acute respiratory events during ED PSA, including hypoxemia and airway interventions.

LIMITATIONS

The acute respiratory event rate observed in our study population was higher than the anticipated pretest projections. The initial projection rate was based on our current PSA database, which may have underrepresented the incidence of acute respiratory events. Alternatively, the elevated acute respiratory event rate observed in the trial may be attributable to a high enrollment of patients with deep sedation encounters or patients deemed to be at higher risk for an acute respiratory event (a sampling bias).

Another limitation to our methodology was the data capture technology used during the study. This technology was not enabled to record continuous ETCO₂ data. To offset this concern, we elected to frequently record patient monitoring data at predefined intervals throughout the clinical encounter. The lack of continuous data capture prevented a precise determination of the onset time of patient monitor changes.

CONCLUSIONS

End-tidal carbon dioxide monitoring of patients undergoing PSA detected many clinically significant acute respiratory events before standard ED monitoring practice did so. The majority of acute respiratory events noted in this trial were preceded by ETCO₂ abnormalities that occurred before changes in SpO₂ or observed hypoventilation and apnea.

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