

## Advances in the Use of Capnography for Nonintubated Patients

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### Abstract

This article reviews recent advances in the use of capnography as a diagnostic monitoring modality for nonintubated patients. These include assessing the response to treatment in patients in acute respiratory distress, determining the adequacy of ventilation in patients with altered mental status (including drug-induced alterations in consciousness during procedural sedation and analgesia and patient-controlled analgesia), assessing the ventilatory status of actively seizing patients, and detecting metabolic acidosis in patients with diabetes and gastroenteritis.

**MeSH Words:** Capnography, end-tidal CO<sub>2</sub>, nonintubated

### Introduction

Although the standard of care in anesthesia practice is well established for intubated patients, there has been little emphasis on the use of capnography in nonintubated patients outside of the operating room. Capnography has many clinical applications in both intubated and nonintubated patients and has been found valuable by emergency medicine physicians and Emergency Medical Services (EMS) in the prehospital as well as in-hospital setting. In addition to confirming the placement of the endotracheal tube and monitoring the tube position during transport, capnography can provide qualitative and quantitative assessments of cardiac output, gauge the effectiveness of cardiopulmonary resuscitation during cardiac

arrest, determine prognosis in cases of cardiopulmonary resuscitation and trauma, titrate end-tidal carbon dioxide (EtCO<sub>2</sub>) levels in patients with suspected increases in intracranial pressure, assess response to treatment in patients in acute respiratory distress, determine the adequacy of ventilation in patients with altered mental status (including drug-induced alterations in consciousness during non-operating-room anesthesia), assess the ventilatory status of actively seizing patients, and detect metabolic acidosis in patients with diabetes and gastroenteritis. The purpose of this article was to review the uses of capnography in nonintubated patients in emergency medicine and to discuss recent advances in its application as a diagnostic monitoring modality.

### Indications for Capnography in Nonintubated Patients

The use of capnography in nonintubated patients has been studied in a variety of conditions (Table 1)

**Table 1.**

Clinical applications of capnography in nonintubated patients
Rapid assessment of airway, breathing, and circulation in critically ill or injured patients
Assessment of ventilatory status of actively seizing patients
Assessment and triage of victims of chemical terrorism
Assessing response to treatment for patients in acute respiratory distress
Determining adequacy of ventilation in patients with altered mental status
Detection of diabetic ketoacidosis
Detection of metabolic acidosis in gastroenteritis

#### *Assessment of Critically Ill or Injured Patients*

Airway integrity, breathing, and circulation can be rapidly assessed in critically ill or injured patients using the capnogram and EtCO<sub>2</sub> values (Fig. 1). The presence of a normal waveform denotes a patent airway and spontaneous breathing [1,2]. Normal EtCO<sub>2</sub> levels signify adequate perfusion [2,3]. Because the CO<sub>2</sub> measurement is airway-based and not muscle-based, capnography does not misinterpret motion artifacts and provides reliable readings in low-perfusion states.

#### *Assessment of Ventilatory Status in Seizing Patients*

Capnography is the only accurate and reliable modality available for monitoring actively seizing patients [4,5]. On the basis of capnographic data (capnogram, EtCO<sub>2</sub>, respiratory rate), physicians and paramedics can distinguish among actively seizing patients with central apnea (flatline waveform, no EtCO<sub>2</sub> readings, no chest wall movement), actively seizing patients with ineffective ventilation and low tidal volume breathing (small waveform, low EtCO<sub>2</sub> values), and actively seizing patients with effective ventilation (normal waveform, normal EtCO<sub>2</sub> values).

#### *Assessment of Victims of Chemical Terrorism*

EMS systems have intensively focused on training in the effective management of mass casualty chemical terrorism events. Capnography provides a noninvasive assessment of the airway, breathing, and circulation and can facilitate the rapid identification of the common life-threatening complications of nerve gas exposure (Table 2) [4,6,7]. It can rapidly detect adverse events in the airway, respiratory, and central nervous system associated with nerve agents, including apnea, upper airway obstruction, laryngospasm, bronchospasm, and respiratory failure.

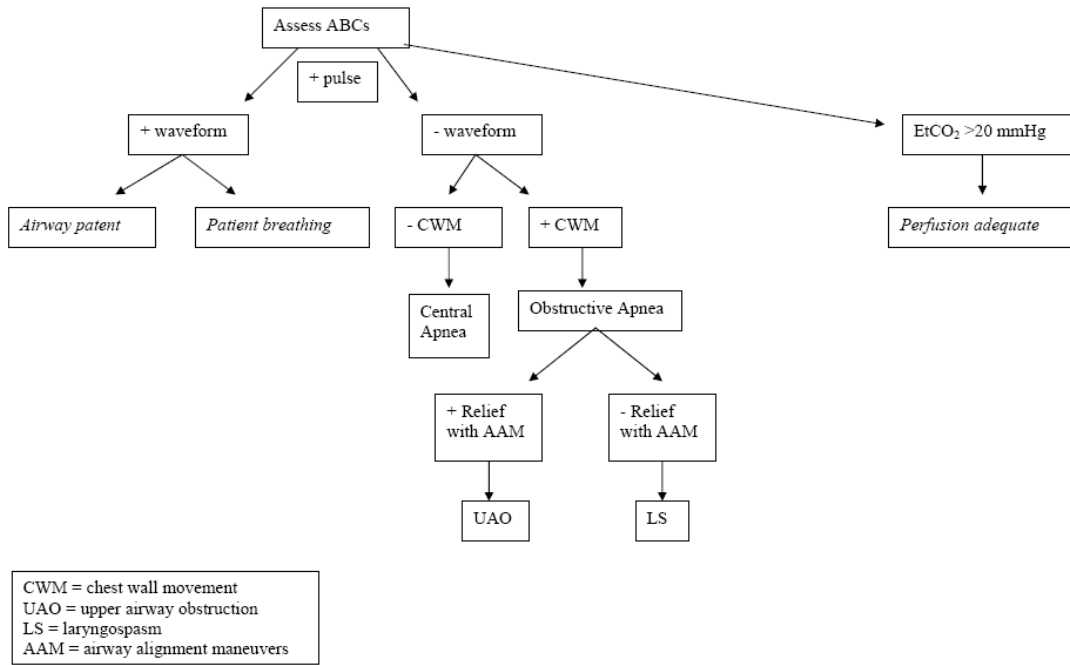
#### *Assessment of Response to Treatment in Patients in Acute Respiratory Distress*

Capnography may serve as a dynamic tool for monitoring the ventilatory status of patients in acute respiratory distress due to asthma, bronchiolitis, chronic obstructive pulmonary disease, congestive heart failure, croup, and cystic fibrosis. By measuring respiratory rate and EtCO<sub>2</sub> with each breath, capnography provides the clinician with instantaneous feedback.

Because the respiratory rate is measured directly from the airway via a nasal-oral cannula, the readings are more reliable than with impedance respiratory monitoring. In patients with obstructive apnea, impedance monitoring may interpret chest wall movements as a valid breath and display a respiratory rate even though the patient is not ventilating. By contrast, the capnogram will show a flatline waveform.

In tachypneic patients, EtCO<sub>2</sub> trends can be rapidly assessed with capnography. A patient with a respiratory rate of 30 breaths per minute will produce 150 EtCO<sub>2</sub> readings in 5 minutes. This provides sufficient information for the physician or paramedic to determine the vector of the patient's ventilatory status: worsening despite treatment (increasing EtCO<sub>2</sub> from baseline); stabilizing (stable EtCO<sub>2</sub>); or improving (decreasing EtCO<sub>2</sub> from baseline). In some patients, it may be helpful to determine if there is a difference between the EtCO<sub>2</sub> and the partial pressure of carbon dioxide (pCO<sub>2</sub>) and to quantify the gradient [8,9]. With correction for the gradient, the EtCO<sub>2</sub> trends can then be used as a substitute for serial pCO<sub>2</sub> measurements.

**Figure 1**  
Capnographic Assessment of Airway, Breathing, and Circulation



**Table 2. Capnography identification of potential life-threatening complications of chemical agents.**

Agent	Effects	Capnography
<u>Nerve gas</u> <ul style="list-style-type: none"> <li>• Tabun</li> <li>• Sarin</li> <li>• Soman</li> <li>• VX</li> </ul>	Seizures, diaphragmatic weakening or paralysis, hypoventilation, respiratory depression, apnea, loss of consciousness/coma	<ul style="list-style-type: none"> <li>• Accurate readings during seizure activity (RR, EtCO<sub>2</sub>, waveform)</li> <li>• Earliest indicator of respiratory compromise</li> </ul>
<u>Vesicants</u> <ul style="list-style-type: none"> <li>• Mustard gas</li> <li>• Lewisite</li> </ul>	Airway edema, upper airway obstruction, bronchospasm	<ul style="list-style-type: none"> <li>• Rapid identification of upper airway obstruction</li> <li>• Rapid identification of bronchospasm</li> </ul>
<u>Choking agents</u> <ul style="list-style-type: none"> <li>• Chlorine</li> <li>• Phosgene</li> <li>• Diphosgene</li> <li>• Chloropicrin</li> <li>• Ricin</li> </ul>	Rapid, progressive, non-cardiogenic pulmonary edema and acute lung injury, bronchospasm, laryngospasm	<ul style="list-style-type: none"> <li>• Earliest indicator of respiratory compromise</li> <li>• Rapid identification of bronchospasm</li> <li>• Rapid identification of laryngospasm</li> </ul>
Cyanide	Sudden loss of consciousness/coma, seizures, metabolic acidosis with tachypnea, apnea	<ul style="list-style-type: none"> <li>• Accurate readings during seizure activity</li> <li>• Earliest indicator of respiratory compromise</li> <li>• Non-invasive identification of metabolic acidosis</li> </ul>
<u>Incapacitating agents</u> <ul style="list-style-type: none"> <li>• Lacrimators (Mace)</li> <li>• Capsaicin</li> </ul>	Laryngospasm, bronchospasm, respiratory failure	<ul style="list-style-type: none"> <li>• Rapid identification of laryngospasm</li> <li>• Rapid identification of bronchospasm</li> <li>• Earliest indicator of respiratory compromise</li> </ul>

*Assessment of Obstructive Lung Disease*

Patients with normal lung function, irrespective of age, have a characteristic rectangular or trapezoid-shaped capnogram and a narrow EtCO<sub>2</sub>-pCO<sub>2</sub> gradient (0-5 mmHg), with the EtCO<sub>2</sub> accurately reflecting the pCO<sub>2</sub> [10]. The capnograms of patients with restrictive lung disease are similar to normal capnograms in six quantitative parameters: EtCO<sub>2</sub> value, respiration rate, take-off angle of the initial expiratory rise, elevation angle for the slope of the alveolar plateau, inspiratory time, and expiratory time (Fig. 2) [11]. However, in patients with abnormal lung function from ventilation-perfusion mismatch, the gradient will widen, depending on the severity of the lung disease, and the EtCO<sub>2</sub> will be useful for trending the ventilatory status, but not as a spot check which may or may not correlate with the concentration of carbon dioxide in arterial blood (PaCO<sub>2</sub>) [8,9]. The capnograms of patients with obstructive lung disease are characterized by a more rounded ascending appearance during the initial phase of exhalation and an upward slope during the alveolar plateau (Fig. 2) [11]. This shape correlates with the changes in forced expiratory volume in one second (FEV<sub>1</sub>) and peak expiratory flow rate [10-14]. The marked differences from the normal capnogram, particular in the angles of the initial expiratory rise and in the alveolar plateau, are progressive, and their magnitude increases with increasing severity of the respiratory impairment (as documented by a decreasing FEV<sub>1</sub>) (Figs. 3,4). The differences from the normal capnogram are sufficiently large to suggest that capnography may be used as a non-effort-dependent method for distinguishing patients with obstructive lung disease from patients with normal lung function [11].

The capnogram is also useful as an objective measure of ventilatory status in asthmatic patients who are unwilling or unable to cooperate with spirometry (e.g., young children, patients on mechanical ventilation, and patients in acute respiratory distress) [12,13]. With further study, the capnogram may also prove beneficial as a screening tool to identify subjects who have underlying obstructive lung disease or patients who may be at risk of acquiring lower airway obstruction during procedural sedation and analgesia.

*Assessment of the Adequacy of Ventilation in Patients with Altered Mental Status*

Obtunded or unconscious patients, including those with alcohol intoxication or intentional or unintentional drug overdose and postictal patients (especially those treated with benzodiazepines), may have impaired ventilation. Capnography can differentiate patients with effective and ineffective ventilation as well as provide continuous monitoring of ventilatory trends over time so patients at risk of respiratory depression and respiratory failure can be identified.

*Procedural Sedation and Analgesia*

Capnography can detect the common adverse airway and respiratory events associated with procedural sedation and analgesia [15]. It is the earliest indicator of airway or respiratory compromise, which manifests as an abnormally high or low EtCO<sub>2</sub> before pulse oximetry detects a falling oxyhemoglobin saturation, especially in patients receiving supplemental oxygen.

Capnography can also rapidly detect both central and obstructive apnea during sedation. Loss of the waveform in conjunction with an absence of chest wall movement and absence of breath sounds on auscultation confirms the diagnosis of central apnea. Complete obstructive apnea is also characterized by loss of the waveform and absence of breath sounds, but chest wall movement is present. Response to airway alignment maneuvers can further distinguish upper airway obstruction from laryngospasm (Table 3).

Capnography may be more sensitive for the detection of apnea during sedation than the clinical assessment of ventilation. In a recent study, 10/39 (26%) patients experienced 20-second periods of apnea during procedural sedation and analgesia. All 10 episodes were detected by capnography but not by the anesthesia providers [16]. Further studies have confirmed the difficulty with which clinicians recognize prehypoxic respiratory depression without the help of capnography [17-21].

The amplitude of the capnogram is determined by the EtCO<sub>2</sub> and its width is determined by the expiratory time. Therefore, changes in these

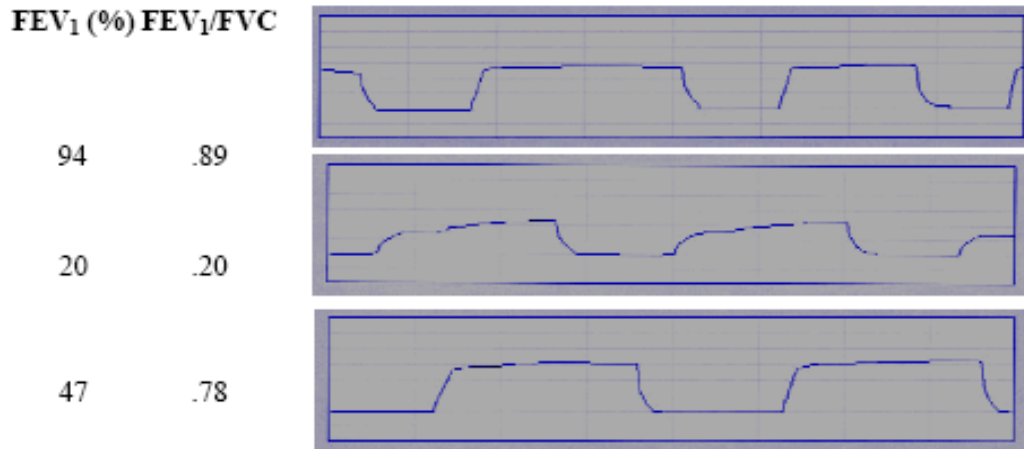


Figure 2. Capnogram shape in normal subjects and patients with obstructive and restrictive lung disease.

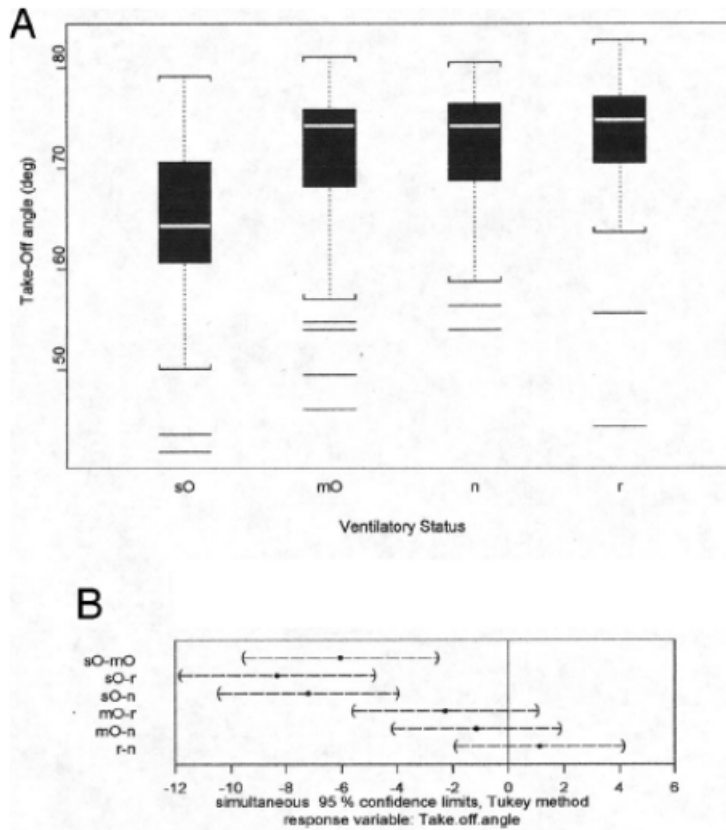
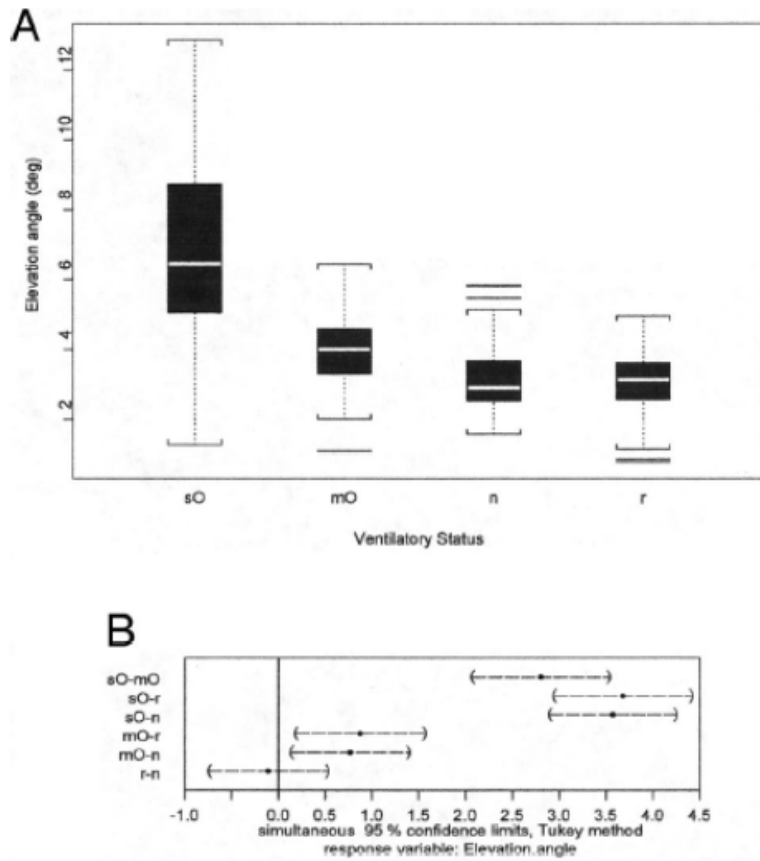
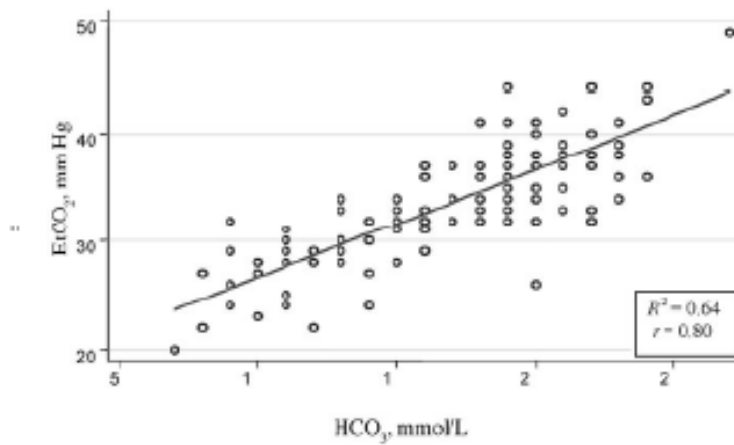


Figure 3. Take-off angle for each ventilatory condition with confidence intervals. sO = severe OD, mO = moderate OD, n = normal, r = restrictive lung disease.

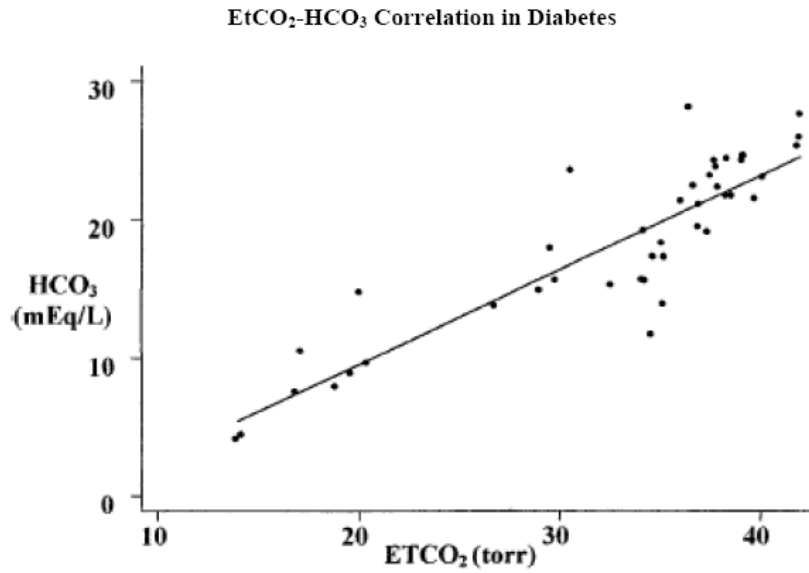


**Figure 4.** Elevation angle for each ventilatory condition with confidence intervals. sO = severe OD, mO = moderate OD, n = normal, r = restrictive lung disease.

### EtCO<sub>2</sub>-HCO<sub>3</sub> Correlation in Gastroenteritis

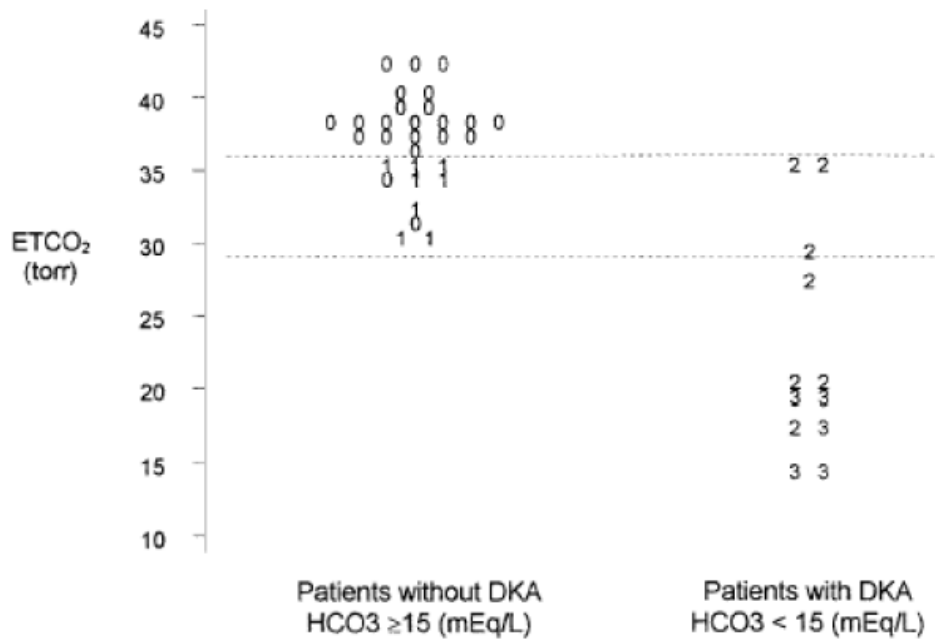


**Figure 5.** EtCO<sub>2</sub>-HCO<sub>3</sub> Correlation in Gastroenteritis.



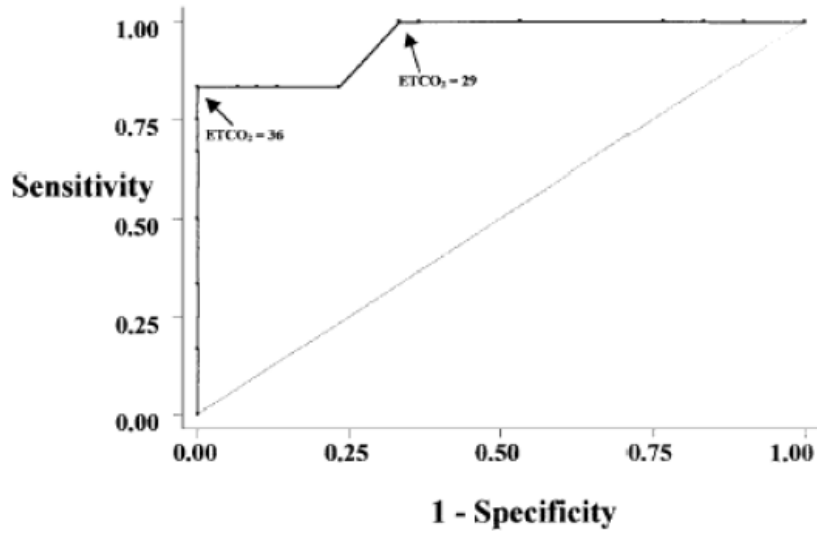
**Figure 6.** EtCO<sub>2</sub>-HCO<sub>3</sub> Correlation in Diabetes.

**Predictive Value of EtCO<sub>2</sub> in Detecting Metabolic Acidosis in Diabetics**



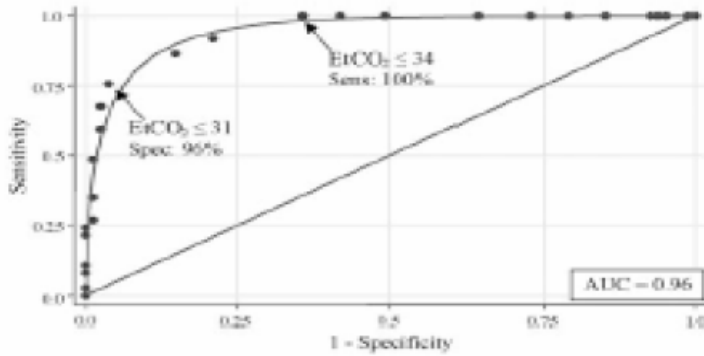
**Figure 7.** Predictive Value of EtCO<sub>2</sub> in Detecting Metabolic Acidosis in Diabetics.

Receiver Operating Characteristic Curve Showing Discriminatory Value of EtCO<sub>2</sub> in Predicting Diabetic Ketoacidosis



**Figure 8.** Receiver Operating Characteristic Curve Showing Discriminatory Value of EtCO<sub>2</sub> in Predicting Diabetic Ketoacidosis.

Predictive Value of EtCO<sub>2</sub> in Detecting Metabolic Acidosis in Gastroenteritis



**Figure 9.** Predictive Value of EtCO<sub>2</sub> in Detecting Metabolic Acidosis in Gastroenteritis.

parameters affect the capnogram shape. Hyperventilation results in a low amplitude and narrow capnogram. Of the two types of drug-induced hypoventilation that may occur during nonoperating room anesthesia, bradypneic hypoventilation (type 1), commonly seen with opioids, is characterized by an increase in expiratory time,  $\text{EtCO}_2$ , and  $\text{PaCO}_2$ . The depression in respiratory rate is proportionally greater than the depression in tidal volume. This process is represented graphically by a high-amplitude and wide capnogram (Table 3). By contrast, hypopneic hypoventilation (type 2), commonly seen with sedative-hypnotic drugs, is characterized by no change or a decrease in  $\text{EtCO}_2$  and an increase  $\text{PaCO}_2$ , as the airway dead space remains constant and tidal volume decreases. The depression in tidal volume is proportionally greater than the depression in respiratory rate. This results in low tidal volume breathing which leads to an increase in the airway dead space fraction (dead space volume/tidal volume) and, in turn, an increase in the  $\text{EtCO}_2$ - $\text{PaCO}_2$  gradient. This process is represented by a low-amplitude capnogram (Table 3).

Bradypneic hypoventilation follows a predictable course, with  $\text{EtCO}_2$  increasing progressively in a linear fashion until respiratory failure and apnea occur. Hypopneic hypoventilation, however, follows a variable, unpredictable, course: the  $\text{EtCO}_2$  could remain stable, with resolution of the low tidal volume breathing over time as central nervous system drug levels decrease and redistribution to the periphery occurs; or periodic breathing with intermittent apneic pauses, which may either resolve spontaneously or progress to central apnea.

The low tidal volume breathing that characterizes hypopneic hypoventilation increases dead space ventilation when normal compensatory mechanisms are inhibited by drug effects. Minute ventilation, which normally increases to compensate for an increase in dead space, does not change or may decrease. As minute ventilation decreases, arterial oxygenation decreases. However,  $\text{EtCO}_2$  may initially be high (bradypneic hypoventilation) or low (hypopneic hypoventilation) without a significant change in oxygenation, particularly if supplemental oxygen is given. Therefore, a drug-induced increase or decrease in  $\text{EtCO}_2$  does not

necessarily lead to oxygen desaturation and may not require intervention.

#### *Pain Management*

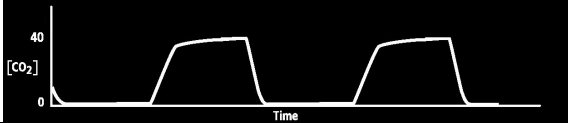
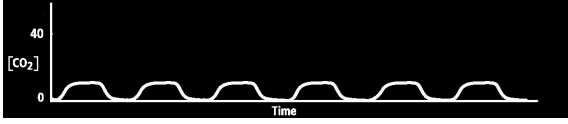
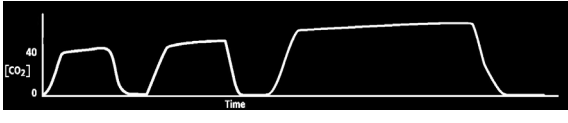



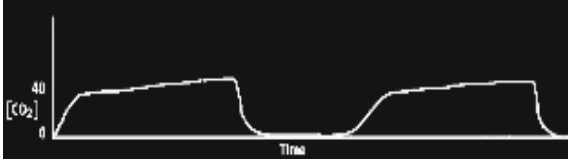
Patient-controlled analgesia (PCA) is currently monitored by pulse oximetry in the general medical or general pediatric wards and the Emergency Department. Capnography is not routinely used. Does monitoring ventilatory status during PCA have added value? In a study of 178 postoperative patients in the surgical ward using a PCA delivery system who were monitored with continuous pulse oximetry and capnography, investigators noted that 12% had desaturation to  $<90\%$  for 3 minutes or more and 41% had respiratory depression (respiratory rate  $<10$  breaths/minute) for 3 minutes or more [21]. These findings indicate that the integration of continuous oxygenation and ventilation monitoring in PCA delivery systems may allow for the future development of safety algorithms based on physiological parameters instead of lock-out times and absolute drug doses [21-23].

#### *Detection of Metabolic Acidosis*

In addition to its established uses for the assessment of ventilation and perfusion, capnography is a valuable tool for assessing metabolic status. Specifically, it provides accurate information on how effectively  $\text{CO}_2$  is being produced by the cellular metabolism.

Recent studies have shown that  $\text{EtCO}_2$  and serum bicarbonate ( $\text{HCO}_3^-$ ) are linearly correlated in patients with diabetes or gastroenteritis and that  $\text{EtCO}_2$  can be used as an indicator of metabolic acidosis in these patients (Figures 5,6) [24-26]. As patients become acidotic,  $\text{HCO}_3^-$  decreases and a compensatory respiratory alkalosis develops, with an increase in minute ventilation and a resultant decrease in  $\text{EtCO}_2$ . The increasing minute ventilation makes it possible to lower arterial carbon dioxide tension and, thereby, correct the underlying acidemia. The more acidotic the patient, the lower the  $\text{HCO}_3^-$ , and the higher the respiratory rate and lower the  $\text{EtCO}_2$ .  $\text{EtCO}_2$  can therefore serve as a marker to distinguish diabetic patients who have ketoacidosis (metabolic acidosis, compensatory tachypnea, low  $\text{EtCO}_2$ ) from diabetic patients who do not (nonacidotic, normal respiratory rate, normal  $\text{EtCO}_2$ ) (Figures 7,8).

**Table 3. Capnographic Airway Assessment in Non-operating Room Anesthesia.**

Diagnosis	Waveform	Features	Intervention	
Normal		SpO <sub>2</sub> EtCO <sub>2</sub> Waveform RR	Normal Normal Normal Normal	No intervention required Continue sedation
Hyperventilation		SpO <sub>2</sub> EtCO <sub>2</sub> Waveform RR	Normal ↓ decreased amplitude and width ↑	
Bradypneic hypoventilation (type 1)		SpO <sub>2</sub> EtCO <sub>2</sub> Waveform RR	Normal ↑ Increased amplitude and width ↓↓↓	Reassess patient and continue sedation
		SpO <sub>2</sub> EtCO <sub>2</sub> Waveform RR	↓ ↑ Increased amplitude and width ↓↓↓	Reassess patient Assess for airway obstruction Supplemental oxygen Cease drug administration or reduce dosing
Hypopneic hypoventilation (type 2)		SpO <sub>2</sub> EtCO <sub>2</sub> Waveform RR	Normal ↑ Decreased amplitude ↓↓↓	Reassess patient Continue sedation
		SpO <sub>2</sub> EtCO <sub>2</sub> Waveform RR	↓ ↓ Decreased amplitude ↓	Reassess patient Assess for airway obstruction Supplemental oxygen Cease drug administration or reduce dosing
Hypopneic hypoventilation with periodic breathing		SpO <sub>2</sub> EtCO <sub>2</sub> Waveform RR Other	Normal or ↓ ↓ Decreased amplitude ↓ apneic pauses	
Physiological variability		SpO <sub>2</sub> EtCO <sub>2</sub> Waveform RR	Normal Normal Varying* Normal	No intervention required Continue sedation
Bronchospasm		SpO <sub>2</sub> EtCO <sub>2</sub> Waveform RR Other	Normal or ↓ Normal, ↑, or ↓** Curved Normal, ↑, or ↓** wheezing	Reassess patient Bronchodilator therapy Cease drug administration

Partial airway obstruction		SpO <sub>2</sub> EtCO <sub>2</sub> Waveform RR Other	Normal or ↓ Normal Normal Variable Noisy breathing and/or inspiratory stridor	Full airway patency restored w/ airway alignment	Reassess patient Establish IV access Supplemental oxygen (as needed) Cease drug administration
Partial laryngospasm				Airway not fully patent with airway alignment	
Apnea		SpO <sub>2</sub> EtCO <sub>2</sub> Waveform RR Other	Normal or ↓*** Zero Absent Zero No chest wall movement or breath sounds	Reassess patient Stimulation Bag mask ventilation Reversal agents (where appropriate) Cease drug administration	
Complete airway obstruction				Airway patency restored with airway alignment	
Complete laryngospasm		SpO <sub>2</sub> EtCO <sub>2</sub> Waveform RR Other	Normal or ↓*** Zero Absent Zero Chest wall movement and breath sounds present	Waveform present	Positive pressure ventilation
				Airway not patent with airway alignment	No waveform

A study of diabetic children presenting to the Emergency Department showed that an EtCO<sub>2</sub> of <29 mmHg identified 95% of the patients with ketoacidosis with 83% sensitivity and 100% specificity [24]. Conversely, no ketoacidosis was detected in patients with an EtCO<sub>2</sub> >36 mmHg. Using these data, nursing triage protocols can be developed to facilitate the assessment and treatment of patients with diabetic ketoacidosis. EtCO<sub>2</sub> is similarly correlated with and predicts HCO<sub>3</sub> level in children with gastroenteritis [26], with maximal sensitivity occurring at EtCO<sub>2</sub> ≤34 mmHg (sensitivity 100%, specificity 60%), and optimal specificity without compromise of sensitivity occurring at EtCO<sub>2</sub> ≤31 mmHg (sensitivity 76%, specificity 96%) (Fig. 9). As a potential triage tool for determining the need for oral vs. intravenous rehydration, EtCO<sub>2</sub> could help identify patients with a clinically significant acidosis. An EtCO<sub>2</sub> of ≤31 mmHg has a positive likelihood ratio of 20.4 for detecting HCO<sub>3</sub> of ≤15 mmol/L and a positive likelihood ratio of

14.1 for detecting HCO<sub>3</sub> ≤13 mmol/L. These EtCO<sub>2</sub> values are 14 or 20 times more likely to occur in an acidotic patient than in a patient with HCO<sub>3</sub> >13 or >15 mmol/L.

### Limitation of Capnography

Significant technical problems in the older generation capnography systems limited their effective use in nonintubated patients and restricted their clinical applications. These included interference with the sensor by condensed water and patient secretions in both mainstream and high-flow sidestream devices, cross sensitivity with anesthetic gases in conventional CO<sub>2</sub> sensors, lack of ruggedness for intra- and interhospital transport, and power consumption problems related to portable battery operation time. All have been resolved in the newer generation capnography monitors [27]. However, problems with accuracy continue to

affect high-flow sidestream systems. When the tidal volume of the patient drops below the flow rate of the system (e.g., in neonates, infants, and hypoventilating patients with low tidal volume breathing), the monitor will entrain room air to compensate, falsely diluting the EtCO<sub>2</sub> and slurring the ascending phase of the waveform [28-30].

The early capnography airway interfaces provided sometimes inconsistent measurements in mouth-breathing patients and patients who alternated between mouth and nose breathing. This problem, too, has been corrected, and the newer nasal-oral airway interfaces can simultaneously sample CO<sub>2</sub> and deliver low-flow oxygen. This allows for preoxygenation and continuous oxygen delivery during procedural sedation and analgesia.

Capnography is most effective for assessing a pure ventilation, perfusion, or metabolism problem. The findings are more difficult to interpret in conditions of mixed ventilation, perfusion, or metabolism. In patients with a complex pathophysiology, a ventilation problem may elevate EtCO<sub>2</sub> while a perfusion problem may simultaneously lower EtCO<sub>2</sub>.

### Conclusion

Capnography is a versatile noninvasive diagnostic monitoring modality for use in both intubated and nonintubated patients. Clinical applications include assessing vital signs in critically ill or injured patients, assessing ventilatory status in actively seizing patients, tracking response to treatment in patients with acute respiratory distress, monitoring ventilation in unconscious or obtunded patients, and detecting the degree of metabolic acidosis in children with diabetes or acute gastroenteritis.

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