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Noninvasive Monitoring of End-Tidal Carbon Dioxide in the Emergency Department

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Abstract
Noninvasive monitoring of end-tidal carbon dioxide ($ETCO_2$) is not new technology but its routine use in the emergency department is a recent development. It is a better tool to evaluate ventilation when compared to oximetry because it provides the caregiver with breath-to-breath information. End-tidal carbon dioxide reflects the production, transportation, and elimination of CO_2. This technology has been used to evaluate endotracheal tube placement. Now with both side stream and mainstream monitoring available, emergency departments can use $ETCO_2$ in a variety of situations. The emergency nurse needs to be able to evaluate the configuration of the waveform in addition to the numeric value. **Key words:** capnography, emergency department, end-tidal CO_2, $ETCO_2$, $PetCO_2$

NONINVASIVE monitoring of end-tidal carbon dioxide ($ETCO_2$, $EtCO_2$, or $PetCO_2$), also known as capnography, is not new technology but its routine use in emergency care is a recent development. For many years emergency nurses have used pulse oximetry to monitor oxygenation. Sometimes called the 5th vital sign, pulse oximetry has limitations because there is a slight time delay before oxygen saturation reflects hypoxia. $ETCO_2$ is a better tool to evaluate ventilation because it provides the caregiver with breath-to-breath information. Recent studies have advocated that capnography does in fact improve patient outcomes through the early recognition of hypoventilation, apnea, or airway obstruction, thus preventing hypoxic episodes (Corbo, Bijur, Lahn, & Gallagher, 2005; Hart, Berns, Houck, & Boenning, 1997; McQuillen & Steele, 2000; Miner, Heegaard, & Plummer, 2002; Soto, Fu, Vila, & Miguel, 2004; Tobias, 1999; Vargo et al., 2002).

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Capnography is a continuous noninvasive technique that measures exhaled carbon dioxide. Stated simply, it is the maximum carbon dioxide level reached at the end of each breath. The technology was first developed by Luft in 1943 but the equipment was cumbersome (Bhavani-Shankar, 2006; Tremper, 1992). The technology has now advanced to the point that it is easy to use and provides accurate information. Since 1986, the American Society of Anesthesiologists has considered capnography one of the "basic standards" for monitoring for all patients receiving anesthesia (American Society of Anesthesiologists, Committee on Standards of Care, 2005). As this technology has developed, its utilization by clinicians outside of the operating room/anesthesia realm has grown. For the emergency nurse, $ETCO_2$ is another objective assessment tool that can be used with a variety of patients.

Carbon dioxide is a byproduct of cellular metabolism. It is transported from the tissues in the venous blood to the lungs where it is exhaled into the environment. $ETCO_2$ has been referred to as the "ventilation vital sign" (Eichbrecht, 2001). Ventilation is the movement of air into the lungs and the displacement of carbon dioxide out of the lungs. There must be adequate circulation and ventilation to detect exhaled carbon dioxide.

Normal $ETCO_2$ concentration in the patient with healthy lungs and normal airway conditions is 30–43 mm Hg. $ETCO_2$ values are about equal to the amount of carbon dioxide in the alveoli and are 2–5 mm Hg less than arterial PCO_2 (Eichbrecht, 2001). Normal arterial PCO_2 is 35–45 mm Hg.

$ETCO_2$ monitoring should *not* be seen as a replacement for arterial blood gases (ABGs). ABGs, although invasive, provide more information including oxygenation, ventilation, and acid base balance. ABGs provide information about only one moment in time versus $ETCO_2$, which displays continuous information about ventilation. Therefore, $ETCO_2$ can be used as an early warning system that allows additional time to intervene before the patient is compromised.

TERMINOLOGY

Capnography provides a numeric value for $ETCO_2$ as well as a graphic display or waveform of the concentration of exhaled carbon dioxide in each breath. A capnogram is the plot of carbon dioxide concentration in airway gas measured against time or volume. This waveform depicts the CO_2 concentration throughout each respiratory cycle (a plot of exhaled CO_2 over time). $ETCO_2$ values are expressed as either a percentage (%), partial pressure in millimeters of mercury (mm Hg), or kilopascal (kPa) (Bhavani-Shankar, Kumar, Moseley, & Ahyee-Hallsworth, 1995; D'Mello & Butani, 2002). The standard speed of the waveform going across the screen is 6.25 mm/s to allow the caregiver to see several breaths on one screen. The speed can be increased if necessary. Like an arterial line, the waveform is graphed on a scale that can be adjusted so that the total waveform is visible

EQUIPMENT

$ETCO_2$ can be measured using a disposable colormetric device or a capnometer. Standalone capnometers are available and most bedside monitoring systems now have the capability to continuously monitor $ETCO_2$.

Emergency personnel have used colormetric $ETCO_2$ detectors for years to assess endotracheal (ET) tube placement and for short-term monitoring of ventilatory status. This disposable device provides a qualitative measure of $ETCO_2$ and is based on a chemical reaction rather than on actual measurement of CO_2 molecules. The user looks for a color change with each breath rather than an actual number. The color change at the end of exhalation is then interpreted. The goal is to see a color change with each breath. Depending on the device used, purple or blue indicates low or absent CO_2 concentrations and yellow is seen with high concentrations of CO_2. A colormetric $ETCO_2$ detector does not change color with esophageal intubation or in the presence of inadequate systemic perfusion.

Capnometers can measure $ETCO_2$ by two methods, side stream or mainstream. Both methods are reliable and provide the caregiver with a continuous value and waveform. Either technology may be used for the intubated patient.

The mainstream method employs a sensor or an infrared measuring device placed directly in-line between the ventilator breathing circuit and the ET tube to continuously measure $ETCO_2$ (see Figure 1). The nurse caring for this patient needs to ensure that the sensor is not pulling on the ET tube. Keep the sensor window clear of secretions or significant water vapor to prevent either false high readings

Figure 1. Mainstream cable and adaptors (Courtesy of Philips Medical Systems, Bothwell, WA).

or failure to detect a waveform (D'Mello & Butani, 2002).

Side stream monitoring can be used for both the intubated and nonintubated patients. In the intubated patient, a small adaptor is placed between the ventilator circuit and the ET tube. For the nonintubated patient, side stream monitoring uses a nasal sampling catheter similar to a nasal cannula (see Figure 2). In both cases, a preset quantity of exhaled gas is aspirated from the patient's airway and pumped to the monitor for analysis. CO_2 is measured at the machine. This technique can be used for patients on room air or receiving oxygen via facemask or nasal cannula as a variety of sampling cannulas are available. Because the sample is being pumped to the monitor for measurement, there is a few second delay between sampling and the information appearing on the monitor screen (LaValle & Perry, 1995).

PHYSICS OF GAS MEASUREMENT

Historically, infra-red (IR) spectrography has been the most widely used and cost-effective

Figure 2. Sidestream line (Courtesy of Philips Medical Systems, Bothwell, WA).

technology for measuring CO_2 levels with portable capnometers or modules inserted in a larger monitoring system (LaValle & Perry, 1995). IR spectrography is based on the principle that CO_2 molecules absorb infra-red radiation at specific wavelengths. The capnometer contains special photodetectors tuned to these wavelengths that enable the calculation of CO_2 levels in the breath sample. CO_2 selectively absorbs specific IR wavelengths of 4.3 millimicrons. Because the amount of light absorbed is proportional to the concentration of CO_2, the concentration can be determined by comparing that concentration with a known standard. In other words, the intensity of IR radiation projected through a gas mixture containing CO_2 is diminished by absorption; this allows the CO_2 absorption band of IR to be measured against the source IR, thus identifying a proportion of CO_2 in the gas mixture (D'Mello & Butani, 2002; LaValle & Perry, 1995).

THE ETCO$_2$ WAVEFORM

As the patient breathes, a characteristic waveform is created (see Figure 3). In the past, reference sources have used different methods of labeling the components of the time capnogram waveform. For example, terms such as "PQRS," "ABCDE," "EFGHIJ," and "phases I–IV" have been used. This has resulted in much confusion with teaching and a lack of standardization. Recently, there has been an effort to standardize the nomenclature for the sake of communication, teaching, and research. The following is a description of terminology currently being utilized (Bhavani-Shankar & Philip, 2000; Lumb, 2000; Morgan, Mikhail, Murray, & Larson, 2002).

A time capnogram can be divided into two segments (see Figure 3a), inspiration and expiration. Inspiration has one phase (0). Expiration has three phases (I, II, and III) and it has two angles, alpha (α) and beta (β). During expiration, Phase I represents the CO_2-free gas from the breathing circuit apparatus and anatomical dead space. Phase II represents the rapidly increasing S-shaped curve that is a mixture of dead space and alveolar gas. Phase III, also referred to as the alveolar plateau, represents CO_2-rich gas from the end of expiration. The alveolar plateau almost always has a positive slope, indicating a rising PCO_2.

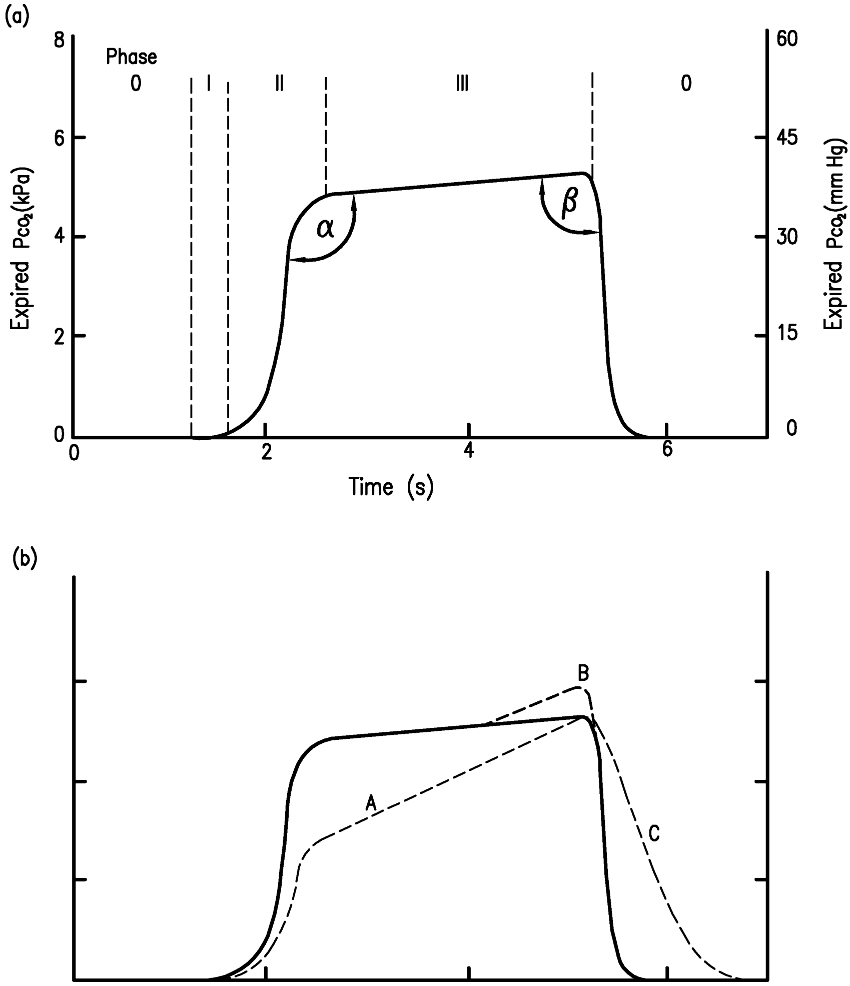

Figure 3. (a) Normal $ETCO_2$ waveform. (b) Dashed line shows $ETCO_2$ waveform abnormalities that may occur separately or together. (A) Varying alveolar time constraints such as asthma; (B) Phase VI terminal upswing seen in pregnancy or obesity; (C) rebreathing of expired gases. Courtesy John Forrestall, Designer, Warrenstreet Architects, Inc, Concord, NH.

This is due to several factors: the alveolar gas that is sampled later in expiration is in fact richer in CO_2, the pulmonary capillaries excrete CO_2 at a constant rate during expiration, and as expiration occurs, the lung volumes decrease thereby increasing the concentration of CO_2 and resulting in a rise in the slope of the alveolar plateau. The angle between Phases II and III is referred to as the alpha (α) angle. It is normally between 100° and 110°. An alpha (α) angle above 110° and a steep slope of Phase III can represent lung pathology, specifically obstructive lung disease such as asthma or chronic obstructive pulmonary disease. The angle in the capnogram between the end of Phase III and the beginning of inspiration (Phase 0) is referred to as the beta (β) angle. It is generally about 90° and does not change unless there is rebreathing of CO_2. Rebreathing CO_2 may be due to excessive apparatus dead space or from a malfunction of the breathing circuit (Lumb, 2002).

In addition to the phases listed above, occasionally, Phase IV is described as an

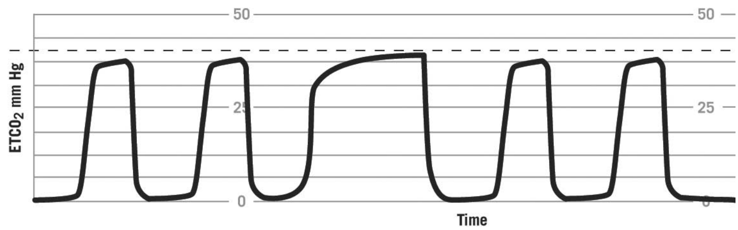

Figure 4. Spontaneous breathing with blunted $ETCO_2$ waveform (Courtesy of Respironics, Pittsburgh, PA).

abnormality in the normal capnogram. An acute increase of the slope at the end of Phase III is called phase IV (Figure 3b). The cause of this is uncertain but may relate to a rapid increase in measured CO_2 due to a small functional residual capacity such as in pregnancy or severe obesity.

The Phase III slope and alpha (α) and beta (β) angles of the capnogram waveform allow the provider to identify abnormalities in ventilation. When reviewing "abnormalities" in the waveform of a time capnogram, it is important to remember that technical problems such as the response time of the analyzer, excessive lengths of sampling tubing, inadequate sampling rates may be the cause of the abnormality that will result in a "blunting" of the waveform (see Fig 4). Measuring CO_2 with a sidestream system via a facemask or nasal canula of a spontaneous breathing patient also produces waveforms that are blunted or less defined than that previously described. The capnogram provides valuable information on a breath-to-breath basis. It can assist the emergency nurse in determining respiratory rate, correct placement of ET tube, approximate arterial CO_2, metabolic rate, and cardiac output.

CLINICAL APPLICATIONS OF $ETCO_2$ MONITORING

Verification of ET Tube Placement

$ETCO_2$ monitoring is used to verify ET tube placement in the trachea. As the patient is ventilated, the exhaled carbon dioxide can be measured with a colormetric device or a capnometer (see Figure 5). The American Heart Association Guidelines for Advanced Cardiac Life Support (ACLS) and Pediatric Advanced Life Support (PALS) call for the use of an $ETCO_2$ device to confirm ET tube placement for all patients with a perfusing rhythm (Cummins, 2003). For the patient with no pulse, the American Heart Association recommends $ETCO_2$ monitoring but, if no CO_2 is detected, another method of tube confirmation should be used. Alternatives include direct visualization of the tube through the cords or an esophageal detector device (Cummins, 2003).

It is recommended that $ETCO_2$ be monitored on all intubated patients during interfacility transport to immediately identify ET tube dislodgement or obstruction (Figure 6). $ETCO_2$ should also be continuously monitored in the intubated pediatric patient as a higher, more anterior glottic opening and a shorter trachea makes accidental dislodgement of the tube more likely.

In addition, many emergency nurses are involved in the transport of intubated, mechanically ventilated patients to radiology or other in-hospital locations. If the patient is ventilated with a bag-valve device during transport, capnography can ensure that the patient is not hypo- or hyperventilated because of variations in the provider's tidal volume or delivered rate.

Cardiopulmonary Resuscitation

Research supports the value of $ETCO_2$ monitoring during cardiac arrest. When a patient arrests, $ETCO_2$ levels fall abruptly because of the absence of cardiac output and pulmonary blood flow. With the initiation of effective

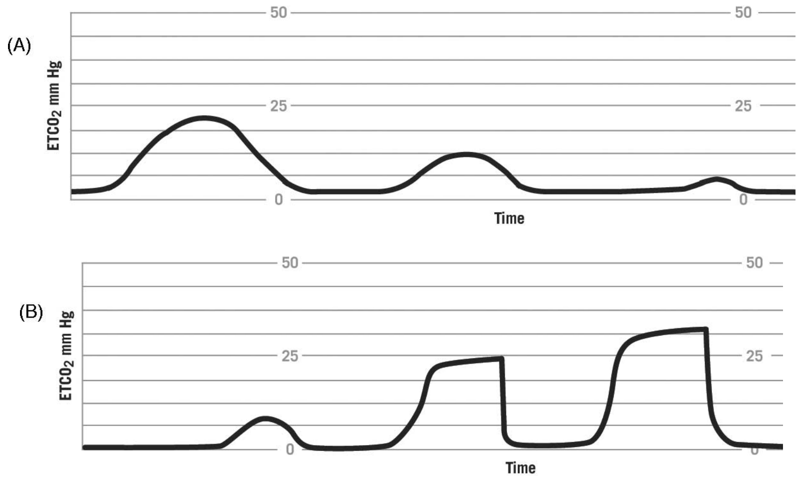

Figure 5. Intubation. (A) Esophageal intubation. (B) Correct endotracheal tube placement (Courtesy of Respironics, Pittsburgh, PA).

cardiac compressions, there will be an increase in $ETCO_2$. As the person performing cardiac compressions becomes fatigued and is no longer compressing effectively, $ETCO_2$ values will fall. With the return of an adequately perfusing rhythm, the $ETCO_2$ value will return to normal levels.

Several studies have looked at $ETCO_2$ values during cardiac arrest to determine whether they can be used to predict outcome. Levine, Wayne, and Miller (1997) concluded that an $ETCO_2$ level of 10 mm Hg or less 20 min after the initiation of ACLS in patients with electrical activity but no pulse can be a predictor of death. Of the 150 cardiac arrest victims included in this study, 35 patients survived to hospital admission. They had an average $ETCO_2$ level of 32.8 ± 7.4 mm Hg after 20 min of ACLS whereas the nonsurvivors had an average $ETCO_2$ level of 4.4 ± 2.9 mm Hg (Levine et al., 1997).

Procedural Sedation

In the emergency department (ED), procedural sedation is used for patients of all ages for a variety of reasons. Medications are administered to raise the pain threshold, decrease anxiety, and provide some amnesia for the event while minimally depressing the patient's level of consciousness. At the same time, the patients maintain their ability to protect their own airway and are able to respond appropriately to verbal commands. The medications used for procedural sedation are often respiratory depressants. In the past, monitoring parameters included vital signs, oxygen saturation, pain rating, and level of

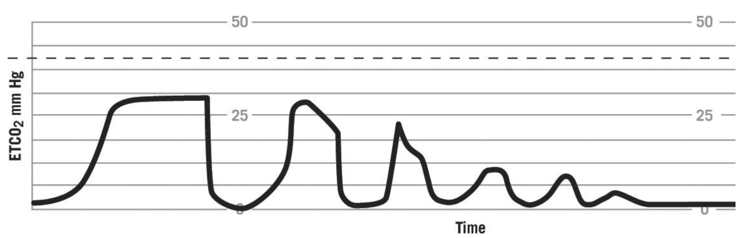

Figure 6. Unplanned extubation. (Courtesy of Respironics, Pittsburgh, PA).

sedation. With the focus on patient safety, optimal monitoring may come to include side stream capnography. Measuring $ETCO_2$ during procedural sedation provides breath-to-breath information and will detect problems such as apnea, respiratory depression, and hypoperfusion. These changes will be seen almost immediately where it may take minutes for oxygen saturation to decrease (Eisenbacher & Heard, 2005). Side steam technology allows the patient to receive oxygen by nasal cannula and at the same time $ETCO_2$ is measured. The nasal cannula used for monitoring $ETCO_2$ delivers oxygen through one prong and pulls an exhaled gas sample through the other prong.

Vargo et al. (2002) demonstrated the usefulness of capnography in adults during procedural sedation. Forty-nine adult patients receiving sedation for an upper endoscopy were monitored using side stream capnography, pulse oximetry, and other standard methods including observation. Endoscopy personnel were blinded to the capnography data. Capnography detected 54 episodes of apnea or "disordered respirations" in 28 patients. Only 50% of these episodes were identified by pulse oximetry. None were identified by visual inspection.

Miner et al. (2002) found that monitoring $ETCO_2$ during procedural sedation could detect respiratory depression. Nearly half (44.6%) of the 74 adults undergoing procedural sedation in an ED experienced respiratory depression. All episodes were identified by capnography (Miner et al., 2002).

The value of $ETCO_2$ monitoring during procedural sedation has been clearly demonstrated; in fact enrollment of patients in one ED study was stopped because of the number of abnormal $ETCO_2$ findings (Burton, Harrah, Germann, & Dillon, 2006). In this study of 60 procedural sedation cases, both adult and pediatric, 36 patients had abnormal $ETCO_2$ findings. In addition, 20 acute respiratory events were documented. In 17 of these 20 acute events (85%), $ETCO_2$ monitoring indicated hypoventilation or apnea. For 70% of these acute events, $ETCO_2$ monitoring identified the change prior to changes in oxygen saturation or observed changes in respiratory rate (Burton et al., 2006).

Prior to sedation, a baseline $ETCO_2$ value should be obtained in addition to observing the waveform. The nurse needs to take into account the effect of pain and anxiety on respiratory rate and depth. During the procedure, look for changes in shape and size of the waveform in addition to significant variation in values and reassess airway, breathing, and circulation status if changes occur. During procedural sedation the respiratory depressant effect of the medications will be seen as a decreased $ETCO_2$ value and a smaller waveform, which drops to 0 during episodes of apnea. When hypoventilation is recognized and the patient is stimulated to breathe, there will be an increase in the amplitude of the waveform and the $ETCO_2$ value (see Figure 7).

Gastric Tube Placement

A relatively new use for $ETCO_2$ monitoring is confirmation that a gastric tube is not in the respiratory tract. Research has repeatedly demonstrated that auscultation is an inaccurate and potentially dangerous way to verify gastric or feeding tube placement (Metheny & Titler, 2001). Radiographic confirmation of correct tube placement is the only reliable

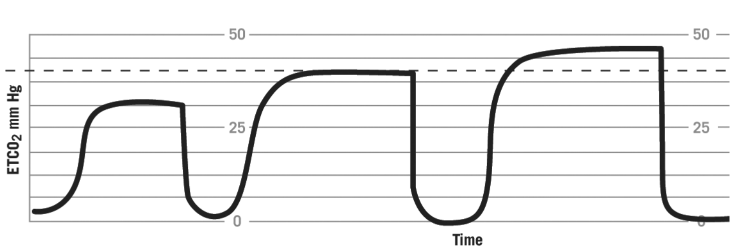

Figure 7. Hypoventilation (Courtesy of Respironics, Pittsburgh, PA).

method of confirming tube placement (American Association of Critical Care Nurses, 2005). $ETCO_2$ has value in verifying that the tube is *not* in the respiratory tract but it does not verify tube location within the gastrointestinal (GI) tract. Hence, $ETCO_2$ is an adjunct method but does not replace other methods of verification (Metheny & Titler, 2001).

Burns, Carpenter, and Truwit (2001) studied 20 adult ventilated patients in a medical intensive care unit during placement of a salem sump tube (13) or a small-bore feeding tube (7). The $ETCO_2$ monitor was attached to the tube during placement. The absence of a CO_2 waveform during placement was consistent with GI placement. Four of the 13 salem sump tubes were initially inserted into the airway, and a CO_2 waveform was observed. The tube was removed and reinserted with no CO_2 waveform observed (Burns et al., 2001).

Araujo-Preza, Melhado, Gutierrez, Maniatis, and Castellano (2002) studied the effectiveness of $ETCO_2$ monitoring, using a colormetric device to verify feeding tube placement in 53 intubated and mechanically ventilated adults. The tube was inserted to a distance of 30 cm, the disposable $ETCO_2$ detector was attached for 1 min and observed for a color change. The feeding tube was then advanced to the appropriate point and second chest X-ray taken. Fifty-two of the 53 feeding tubes were placed in the GI tract, and no color change was observed indicating that no CO_2 was detected. The one tube placed in the trachea demonstrated a color change indicating the presence of carbon dioxide. To verify the sensitivity of this technique, 20 feeding tubes were placed in the trachea through an ET tube. Carbon dioxide was detected in all 20 patients (Araujo-Preza et al., 2002).

Ventilation: Perfusion Assessment

Alveolar dead space is that area of the lung that has no perfusion. Physiologic dead space is the sum of both anatomical dead space and alveolar dead space. In the healthy individual, most physiologic dead space is anatomical. Any significant reduction in lung perfusion (i.e., air embolism, upright position, decreased cardiac output, or hypotension) will increase physiologic dead space (especially alveolar dead space). Normally ventilation (V) is about 4 L/min, and perfusion (Q) is about 5 L/min. Thus they are "nearly balanced" with each other for a V/Q ratio of 0.8. If a mismatch develops, it affects the $ETCO_2$ value. Exhaled CO_2 levels decrease, and the amplitude of the waveform will be decreased. Usually the difference between $ETCO_2$ and $PaCO_2$ is 2–5 mm Hg. With an increase in physiologic deadspace, a V/Q mismatch develops and the difference between $ETCO_2$ and $PaCO_2$ widens. The larger the rise in physiologic deadspace, the bigger the difference in values. For example, with a pulmonary embolus there is a decrease in blood flow to an area of the lung but no change in alveolar ventilation. The $ETCO_2$ value decreases and there is a widening of the difference between $PaCO_2$ and $ETCO_2$ (Ahrens & Sona, 2003).

Asthma and Obstructive Lung Diseases

$ETCO_2$ can be used to assess the severity of an asthma exacerbation and the effectiveness of interventions. $ETCO_2$ values vary with the severity of the episode. Initially, with a mild exacerbation, the patient may hyperventilate and $ETCO_2$ will decrease. With a severe exacerbation, there will be an increase in the alpha angle and a steep sloping ascending limb in the Phase III slope (Figure 8). It has been suggested that this occurs from sequential emptying of "fast" and then "slow" alveoli.[1] The angle of the Phase III slope will depend on the difference between the amount of "fast" versus "slow" alveoli. Typically, bronchospasm of asthmatic origin is proportional to the angle of this slope. The concentration of CO_2 in the "slow" alveoli is much higher. Patients with obstructive lung disease empty the fast alveoli first and then the slow alveoli. With advanced disease, more slow alveoli exist; hence, the slope of Phase III is steeper.

[1] "Fast" aveoli are noncompliant (stiff) with low resistance. "Slow" alveoli are overcompliant (more compliant than normal alveoli) with high resistance and higher CO_2 concentration.

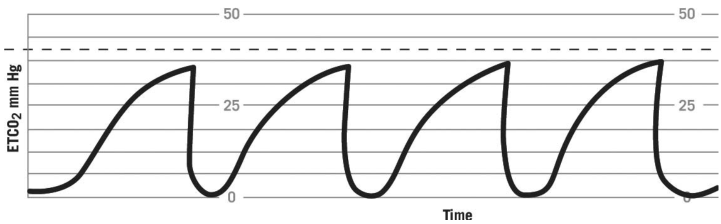

Figure 8. Asthma and airway obstruction. Note increase in the alpha angle and therefore a change in the Phase III slope. A steep sloping ascending limb is also present. (Courtesy of Respironics, Pittsburgh, PA).

The National Asthma Education and Prevention Program Expert Panel 2 report suggests obtaining ABGs to evaluate $PaCO_2$ "in patients with suspected hypoventilation, severe distress, or with an FEV1 or peak flow less than or equal to 30% of predicted after treatment" (National Asthma Education and Prevention Program Second Expert Panel on the Management of Asthma, 1997, p. 28). A study of 39 nonintubated adults experiencing a severe asthma attack found that the agreement between $ETCO_2$ obtained by capnography and $PaCO_2$ obtained from an arterial blood gas was high (Corbo et al., 2005). ABGs are invasive and costly and provide the health-care team information about one moment in time. The early initiation of $ETCO_2$ monitoring will allow the care team to continuously reassess the patient and monitor the effect of interventions.

Low Flow States

The carbon dioxide produced by cellular metabolism is transported in the blood to the lungs for elimination. If for some reason blood flow is inadequate, CO_2 builds up in the underperfused tissues. At the same time, because of the low perfusion of the lungs, less CO_2 is eliminated and the $ETCO_2$ value falls. When blood carbon dioxide levels rise, the patients increase their respiratory rate and depth as a compensatory mechanism in an attempt to eliminate the excess CO_2.

CURRENT RESEARCH

Is capnography a useful noninvasive tool that can be used to rapidly identify the patient with metabolic acidosis? Traditionally, this is determined by ABGs. Sidestream capnography could be initiated upon patient presentation and the waveform and value evaluated as part of the initial assessment. With metabolic acidosis the initial physiologic response is to compensate by increasing minute ventilation (respiratory rate per minute times tidal volume). Therefore, a low-$ETCO_2$ value would be obtained. Limited studies have evaluated the use of capnography to identify metabolic acidosis. More evidence is needed before we change practice.

Fearon and Steele (2002) evaluated the utility of $ETCO_2$ as a predictor of the presence and severity of acidosis in a convenience sample of 42 children being evaluated for diabetic ketoacidosis. They found a significant relationship between serum HCO_3 and $ETCO_2$. In addition, the $ETCO_2$ value in children diagnosed with DKA was significantly lower than that in the rest of the sample.

The most common electrolyte abnormality in children brought to the ED with vomiting and diarrhea is a low-serum HCO_3 level. Nagler, Wright, and Krauss (2006) reported a strong correlation between $ETCO_2$ and serum HCO_3 levels in 130 children with gastroenteritis. They concluded that capnography "offers an objective noninvasive measure of the severity of acidosis in patients with gastroenteritis" (Nagler et al., 2006).

PRACTICAL APPLICATION

A change in the $ETCO_2$ value or waveform is a signal for the nurse to reassess the ABCs. Does the $ETCO_2$ correlate with the patient's other vital signs and assessment findings? Does the value and waveform make sense? Check the patient and the equipment. Is the patient apneic? Is the sample line kinked? Is the ventilator disconnected? Is the ET tube plugged? Is the patient extubated?

INTRODUCING CAPNOGRAPHY TO THE ED: THE BRIGHAM EXPERIENCE

The installation of a new central monitoring system in the ED at Brigham & Women's Hospital brought with it new capabilities. One was the ability to monitor $ETCO_2$. The goals for orientation to this technology were simple: we wanted the nurse caring for the patient with $ETCO_2$ monitoring to be able to set up the equipment, interpret the $ETCO_2$ value and waveform, and apply the information to the patient situation. New technology often raises staff anxiety so it was important that the department have a well-thought-out educational initiative. To facilitate the incorporation capnography into nursing practice, a three-part educational program was developed.

1. *A self-learning packet and post test*. A detailed self-learning packet reviewed the physiology behind $ETCO_2$, the basic principles, and key concepts such as normal and abnormal waveforms. A question-and-answer format was used. Multiple waveforms were included with explanations of what each showed and why. Continuing education credit was awarded. A self-learning packet was chosen because this teaching method was highly rated in a recent staff needs assessment.
2. *Demonstration of the technical skills of setting up, calibrating, and trouble shooting the capnography equipment*. The monitoring company held a train-the-trainer program for the educators and permanent charge nurses. The hands-on component was conducted by the educators on the unit in multiple small group sessions. Both mainstream and side stream capnography was demonstrated, and then each nurse had the opportunity to practice setting it up. Sessions varied in length, depending on the participants and the number of questions. The permanent charge nurses are designated "super users" and are able to answer questions and troubleshoot issues. They provided invaluable advice about the implementation process.
3. *Return demonstration*. For Part 3, the educators have developed several $ETCO_2$ monitoring clinical scenarios. Each nurse will set up both side stream and mainstream monitoring, answer questions about the patient scenarios including interpreting the value and waveform, and identify appropriate nursing interventions. The educators found that using the concepts of CO_2 production, transportation and elimination were helpful to nurses in understanding why $ETCO_2$ values change with different conditions. See Table 1 for a summary of this information.

Table 1. Clinical conditions and effect on capnography values

Clinical condition	Effect on $ETCO_2$	Reason
Hypothermia	Gradual decrease	Decreased production
Hypermetabolic states (sepsis, malignant hyperthermia)	Increase	Increased production
Hyperventilation	Decrease	Increased elimination
Hypotension	Decrease	Decreased transport

SUMMARY

Capnography use in the ED will continue to grow as emergency nurses become more comfortable with the technology and interpretation of waveforms and values. The objective information obtained will assist with patient care decisions and promote safer patient care.

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