

End-Tidal Carbon Dioxide Monitoring

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End-tidal carbon dioxide monitoring refers to the noninvasive measurement of exhaled carbon dioxide and is most useful when applied directly to patient care.¹ Although commonly used in intubated patients receiving mechanical ventilation, this technique is sometimes used in non-intubated patients.²⁻⁴ The term “capnometry” refers to the measurement and display of the concentration of exhaled carbon dioxide either as a percentage (%) or as partial pressure in millimeters of mercury (mm Hg). If the gas measuring device also includes a calibrated, visual waveform recording of the concentrations of inspired and exhaled carbon dioxide that can be examined on a

breath-by-breath basis or for long-term trends, the instrument is called a capnograph.⁴ Although this respiratory monitoring technology is not new to the critical care environment, controversy still exists regarding potential benefits and limitations in clinical practice.⁵ The questions and answers presented here may enhance your understanding of end-tidal carbon dioxide monitoring.

Q: How is end-tidal carbon dioxide measured?

Depending on the type of equipment used, the concentration of inspired and expired carbon dioxide can be measured directly at the patient-ventilator interface (mainstream sensor, Figure 1), or a sample of gases can be collected and transported via small-bore tubing to the bedside monitor (sidestream, distal-diverting; Figure 2) or some intermediate connection (sidestream, proximal-diverting) for measurement.⁶ Concentrations of respired carbon dioxide from the patient’s airway are typically determined by using infrared light. With this method,

the absorption of carbon dioxide molecules exposed to various wavelengths of light within a sample chamber or cell is measured. A photodetector then compares the relative amount of light absorbed by the sample with the amount absorbed by a gas that is free of carbon dioxide. The difference between the two represents the concentration of carbon dioxide.

Another method used to analyze exhaled gases is mass spectrometry, a technique that separates and measures respired gas on the basis of molecular weight.⁴ Finally, end-tidal carbon dioxide may be measured semi-quantitatively using a special colorimetric pH-sensitive indicator that changes color in response to different concentrations of carbon dioxide.⁴

Q: What is the best location for sampling or measuring the end-tidal carbon dioxide concentration in an intubated patient?

Regardless of the type of sampling technique, place the airway adapter or sampling port as close as possible to the patient’s airway.^{4,7} The closer the measuring/sampling adapter is placed to the patient-ventilator connection, the more responsive the monitor will be when detecting a change in the level of exhaled carbon dioxide. Position the airway adapter upright according to the manufacturer’s recommendations. If the airway adapter and sampling ports are not kept upright, water and secretions will pool at the bottom of the adapter and may interfere with the

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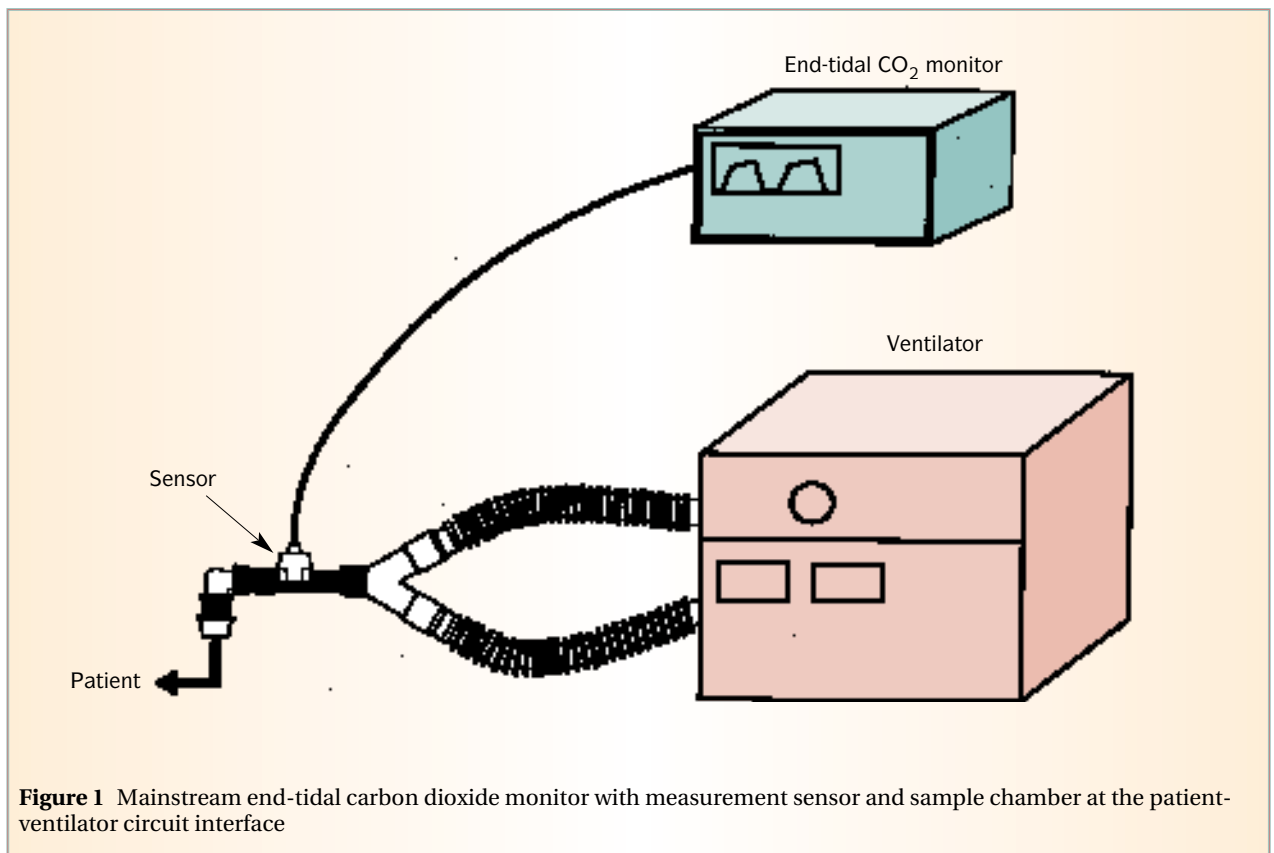


Figure 1 Mainstream end-tidal carbon dioxide monitor with measurement sensor and sample chamber at the patient-ventilator circuit interface

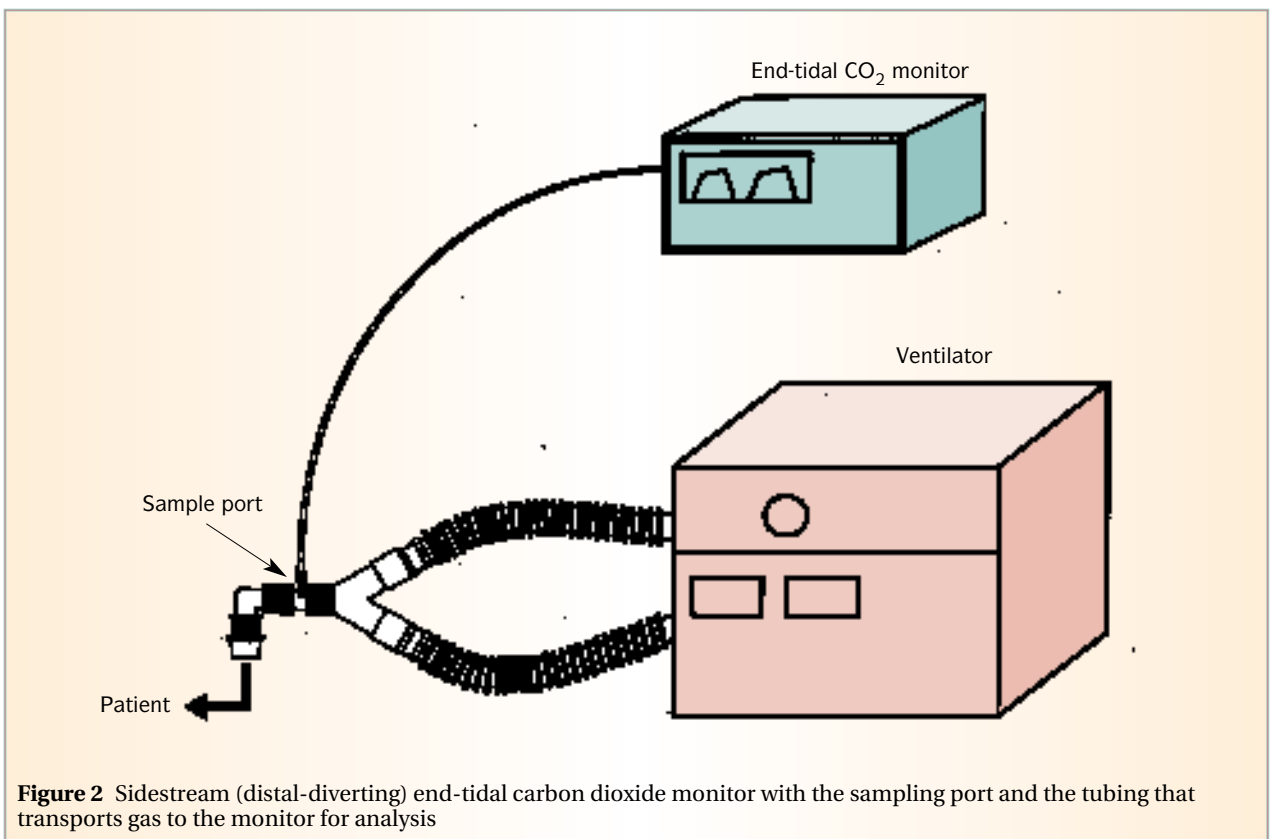


Figure 2 Sidestream (distal-diverting) end-tidal carbon dioxide monitor with the sampling port and the tubing that transports gas to the monitor for analysis

measurement of carbon dioxide. Always support the positioning of the airway adapter or sampling port to minimize pull or weight on the patient's airway.

Q: What is the clinical significance for advocating monitoring of the end-tidal carbon dioxide levels?

The ideal end-tidal carbon dioxide monitor provides both numeric and graphic waveform displays. The display on the monitor represents the highest concentration of carbon dioxide reached at the end of exhalation and is assumed to represent alveolar gas, which under normal ventilation-perfusion matching in the lungs closely parallels arterial levels of carbon dioxide.^{4,6} Thus, the end-tidal carbon dioxide tension (PetCO₂) is thought to be a non-invasive estimate of the patient's alveolar ventilation status by its close correlation with arterial carbon dioxide tension (PaCO₂) under normal conditions.

Unfortunately, unless the patient has a stable cardiac status,

stable body temperature, absence of lung disease, and normal capnogram (Figure 3), the PetCO₂ will not accurately reflect PaCO₂. Therefore, the use of capnography in patients with severe respiratory failure should be interpreted with careful attention. The increased ventilation to perfusion (V/Q) mismatch that is consistent with a increased PaCO₂-PetCO₂ difference or gradient, as well as worsening arterial carbon dioxide retention and increased peripheral carbon dioxide production, may lead to erroneous PetCO₂ values. The normal arterial to end-tidal CO₂ gradient is approximately 1 to 5 mm Hg but may be as high as 20 mm Hg or higher when an uneven V/Q pattern occurs such as when ventilation is greater than perfusion.⁴ Because V/Q matching in critically ill patients is often abnormal, PetCO₂ values must be evaluated cautiously.^{8,9} However, the routine monitoring of the PaCO₂-PetCO₂ gradient may be valuable for determining trends.^{10,11} For example, a gradual narrowing of the gradient over time may represent improved ventilation-perfusion matching

and pulmonary function. Much research is currently under way in evaluating the potential value that capnography brings as a tool for evaluating the effectiveness of cardiopulmonary resuscitation aimed at reestablishing circulation.¹²⁻¹⁴ There is some evidence to suggest that a persistently low PetCO₂ and a widened PaCO₂-PetCO₂ gradient during cardiopulmonary resuscitation as well as intraoperatively during certain surgical procedures, is associated with poor outcomes.^{12,14,15}

Q: Can capnographic waveform displays provide clinically useful information independent of the numerical end-tidal carbon dioxide reading?

It is important to recognize that clinicians should never accept any PetCO₂ value without first determining the quality of the capnogram or end-tidal carbon dioxide waveform. In those situations where the PetCO₂ numerical value is of questionable benefit, inspection of the waveform tracings alone has the

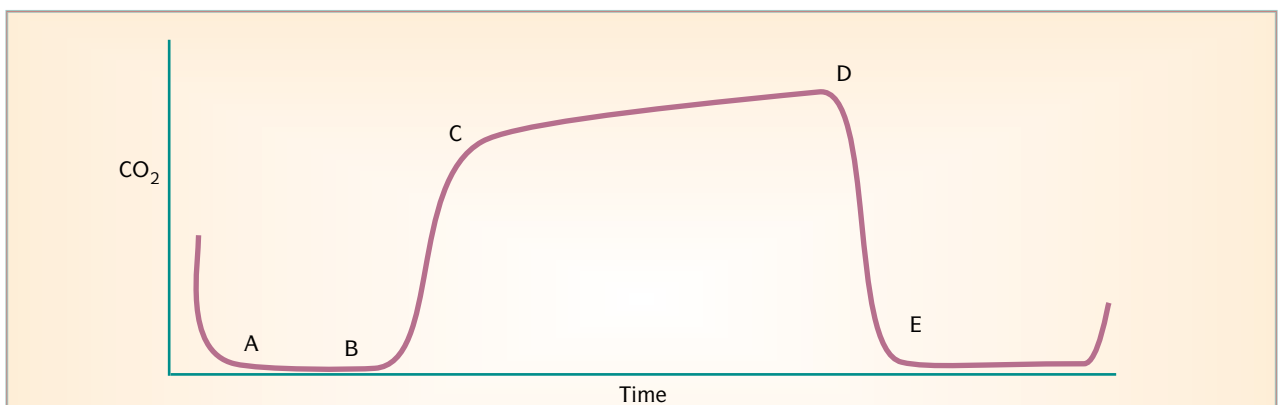


Figure 3 Typical normal carbon dioxide waveform. A to B, exhalation of carbon dioxide-free gas from dead space. B to C, combination of dead space and alveolar gases. C to D, exhalation of mostly alveolar gas (alveolar plateau). D, end-tidal point, that is, exhalation of carbon dioxide at maximum point. D to E, inspiration begins and carbon dioxide concentration rapidly falls to baseline or zero.

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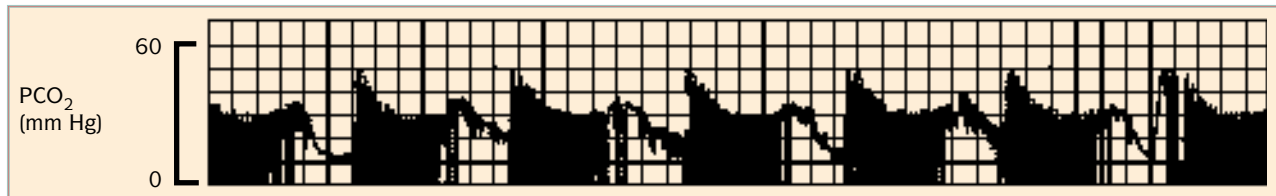


Figure 4 Slow-speed capnogram shows Cheyne-Stokes respirations in a 72-year-old woman who required mechanical ventilation after a cerebral vascular accident. Note the changes in breathing pattern associated with periods of apnea that consistently repeat.

potential to provide the clinician with useful information.^{6,16}

Capnographic waveforms can usually be visualized and recorded at several speeds. In general, the fast-speed recordings provide a real-time display of the carbon dioxide waveform on a breath-by-breath basis. Slow-speed recordings allow for trending over defined time periods.

Figure 4 illustrates the value of using slow-speed recordings to properly identify and document abnormal breathing patterns such as Cheyne-Stokes respirations.

Such tracings could also be helpful when trying to identify the time course in which events such as ventilator system air leaks occur, development of partial or acute airway obstruction, and other important clinical events that might slowly develop over time and which can be detected by capnographic trending.¹⁷ Analysis of real-time breath-by-breath tracings may be useful during mechanical ventilation to detect certain types of equipment malfunction or incorrect ventilator parameter settings that might not

be immediately picked up by the ventilator system alarms. Figure 5 illustrates the effect of respiratory efforts not being sensed by the ventilator because of an improperly set trigger sensitivity control. Real-time capnographic recordings also have the potential to provide qualitative respiratory breathing pattern information during patient weaning efforts from mechanical ventilation, which is important for overall clinical assessment purposes.¹⁶ As shown in Figure 6, analysis of individual tracings may yield informa-

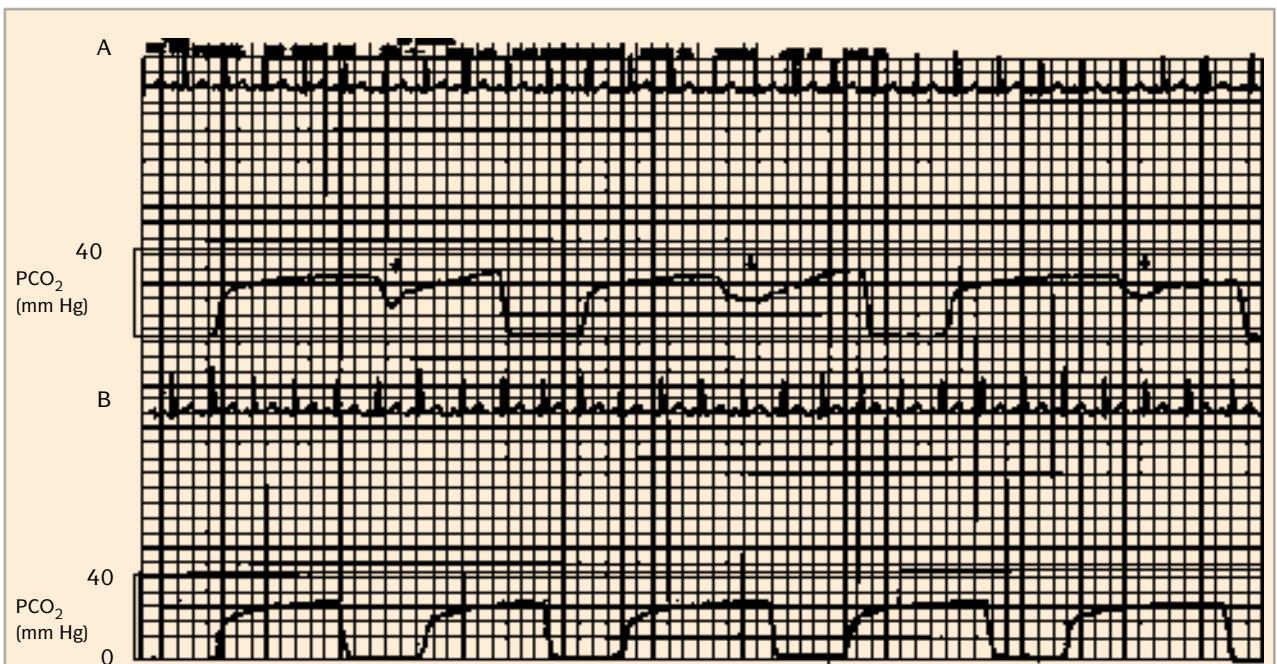


Figure 5 Electrocardiograms and capnograms of a 57-year-old man receiving mechanical ventilation for respiratory failure associated with bacterial pneumonia. A, Respiratory efforts (arrows) are not being sensed by the ventilator because the trigger sensitivity control is set inappropriately. B, Correction of the sensitivity setting allows the patient to trigger the ventilator on demand.

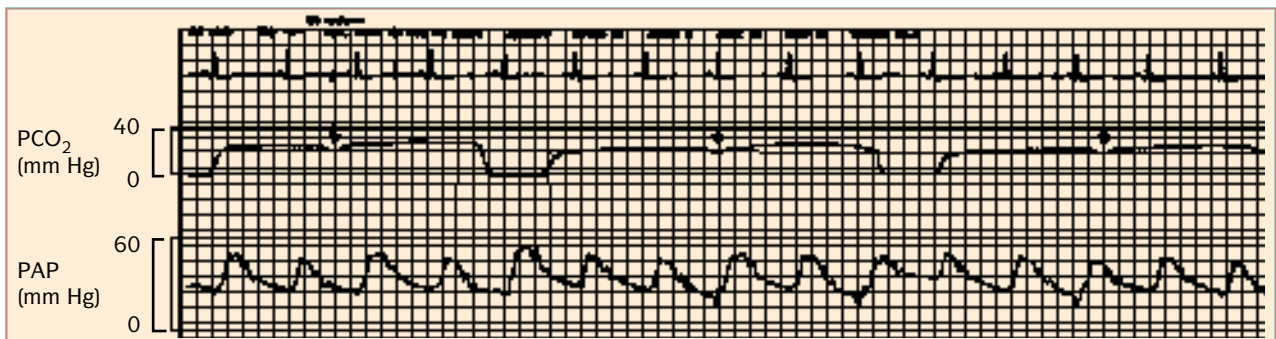


Figure 6 Real-time electrocardiogram, end-tidal carbon dioxide waveforms, and pulmonary artery pressures (PAPs) in a 67-year-old woman who was receiving mechanical ventilation because of respiratory distress and urosepsis. She was also receiving a sedative and a neuromuscular blocking agent. The end-tidal carbon dioxide waveforms show breakthrough spontaneous respiratory efforts (arrows) that are too weak to trigger a ventilator breath.

tion regarding patient response to certain types of drug therapy. There is data to suggest that the slope of the individual capnographic waveform may be helpful in the clinical assessment of patients with asthma in the acute phase of treatment.^{18,19}

Utilizing researched-based, clinical practice protocols has the potential to improve the quality of nursing knowledge in the critical care environment as well as

improve patient care. When appropriately applied, end-tidal carbon dioxide monitoring provides the clinician with valuable information that can assist nurses and others in patient assessment and treatment.

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Clinical pearls for continuous end-tidal carbon dioxide monitoring

Always follow manufacturers' recommendations regarding equipment set-up, sensor placement/sampling as close as possible to the patient-ventilator interface, calibration and maintenance guidelines to help optimize technical accuracy and reliability of measurements. *No numbers are better than wrong numbers.*

Recognize that the end-tidal CO₂ tension (PetCO₂) may not accurately reflect arterial CO₂ tension (PaCO₂) and therefore alveolar ventilation in those patients with absent (ie, cardiac arrest) or abnormal pulmonary blood flow (ie, pulmonary emboli) and in patients with parenchymal lung disease (ie, emphysema). Thus, even the appropriate utilization of capnography may not always equate into a reduced need for obtaining arterial blood gases in certain critically ill patients. *Labeling it doesn't always make it so.*

Documenting the arterial to end-tidal CO₂ difference or gradient (PaCO₂ - PetCO₂) over time may provide important clues related to either improved or worsening patient clinical status. *Isolated end-tidal carbon dioxide readings have less clinical value than multiple measurement and gradient trending over time.*

Always inspect the quality and shape of capnographic waveform first before accepting any numerical end-tidal CO₂ value from a monitoring device. *Numeric PetCO₂ values without waveforms are misleading.*

End-tidal CO₂ waveform monitoring alone either on a breath-by-breath basis or for trending purposes may yield very useful clinical information to complement physical assessment skills and observations. *Routine PetCO₂ waveform monitoring has potential clinical value in patient management.*

Having the availability of sophisticated technologies such as capnography and other hemodynamic or respiratory monitoring systems doesn't dictate its need or usefulness. Primary assessment by the nurse, therapist, or other clinician remains an important aspect of patient monitoring. *Capnography is best utilized as an adjunct aid to, but not a substitute for, direct patient observations and assessment by the clinician.*

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Note: This article is based on the protocol “End-tidal CO₂ Monitoring” by Robert St. John, RN, RRT, MSN, from the *Noninvasive Monitoring Series of AACN’s Protocols for Practice*. Protocols can be obtained from AACN, 101 Columbia, Aliso Viejo, CA 92656-1491, (800) 899-AACN, (949) 362-2000. \$11, AACN members; \$14, nonmembers.

Update 2003

Use of Exhaled Carbon Dioxide Measurement During Placement of Feeding Tubes

Recent data suggest that the measurement of exhaled carbon dioxide may be a useful adjunct in verifying gastric feeding tube placement in critically ill patients.^{1,3} Such patients are typically at high risk for complications related to small- and large-bore feeding tube placement such as, presence of either an endotracheal or tracheostomy tube, altered mental status and/or ability to effectively communicate discomfort. Reportedly, successful bedside measurement techniques used have included both capnography⁴ as well as semiquantitative colorimetric carbon dioxide detection⁵; with the later employing a colorimetric carbon dioxide detector (Easy Cap, Nellcor Puritan Bennett, Pleasanton, Calif). Depending on technique utilized, either the graphic and numeric display of PetCO₂ or colorimetric change (from purple to yellow color) following tube placement indicates that CO₂ is detected and implies misplacement of the feeding tube into the lungs. Further clinical study is warranted for this simple and potentially cost-saving procedure.

Carbon Dioxide Measurement Using Resuscitation Bags

End-tidal carbon dioxide detection and measurement continues

to play an important role as a nonphysical assessment technique for confirming proper endotracheal tube placement following intubation. Recent advances in manual resuscitation bag design now incorporate integral breath-to-breath colorimetric CO₂ detection for initial and ongoing



INdGO manual resuscitator with integral INdCAP carbon dioxide detector.

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verification of proper tube placement for up to 2 hours (see Figure).

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