End-Tidal CO_2 Verification of Endotracheal Tube Placement in Neonates

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The benefits of endotracheal intubation are confined to patients in whom the endotracheal tube is correctly placed in the trachea. The stomach does not exchange gas with the blood stream and ventilating the stomach will quickly lead to hypoxia and death [p. 273].[1]

Abstract

Endotracheal tubes are misplaced more often than one may think, and the consequences of not quickly detecting and correcting the error can be catastrophic. In the pediatric and adult populations, end-tidal CO_2 verification of endotracheal tube placement is considered to be the standard of care. An understanding and use of the technology available are essential for all health care professionals to allow them to provide optimum care for their patients.

ENDOTRACHEAL (ET) TUBES are commonly placed in the delivery room and NICU for reasons including respiratory distress or failure, surfactant administration, and cardiac resuscitation. Studies involving the intubation of neonates in the delivery room or NICU report rates of initial esophageal intubation ranging from 27 percent to 41 percent.[2–4] Failure to correct a misplaced ET tube can have serious, even fatal, results, and many malpractice claims have succeeded in cases in which misplaced ET tubes were unrecognized. Thus, the key to avoiding physical as well as medicolegal problems is the ability to quickly recognize misplaced ET tubes and provide adequate ventilation.[5–8]

Although initial verification of ET tube placement is essential, ongoing assessment and confirmation of proper placement are equally important. The relative size of the neonate's trachea and lack of supporting structures make the neonate more susceptible to extubation. Even after initial verification, simple flexion and extension movements as well as routine handling can cause extubation.[9,10]

Several methods are used to verify proper ET tube placement; but what is the best way to know if an endotracheal tube is actually in the trachea? Do we assess for bilateral breath sounds or sounds in the abdomen? Do we wait for radiographic confirmation with a chest x-ray? This article explores the advantages and benefits of using end-tidal carbon dioxide ($EtCO_2$) detection and monitoring in the initial and ongoing verification of ET tube placement.

METHODS FOR VERIFICATION OF ET TUBE PLACEMENT

A variety of methods can be used to ensure that an ET tube is correctly positioned including direct visualization of x-ray confirmation. While x-ray may be the gold standard in terms of placement, it requires time and equipment that may not be available given the urgency of neonatal intubation.

With direct laryngoscopy, one can visualize the ET tube passing through the vocal cords (Figure 1). Although this is certainly one of the best ways to assess where the tube is at the time of placement, it is not sufficient. The individual performing the intubation may be reasonably assured of proper placement by visualizing the ET tube as it passes through the cords, but problems may arise if the vocal cords are not clearly visible or if the tube should become dislodged before it has been secured. These considerations establish the absolute need for secondary methods of verification.[11,12]

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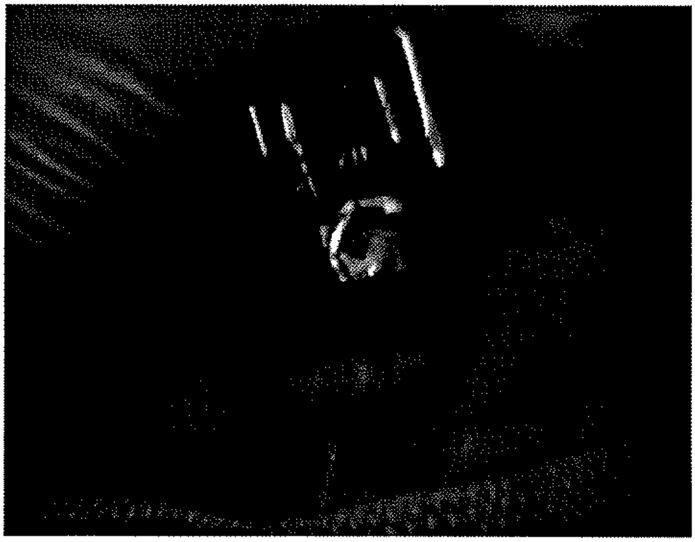
FIGURE 1 ■ Laryngoscope view of pediatric vocal cords.

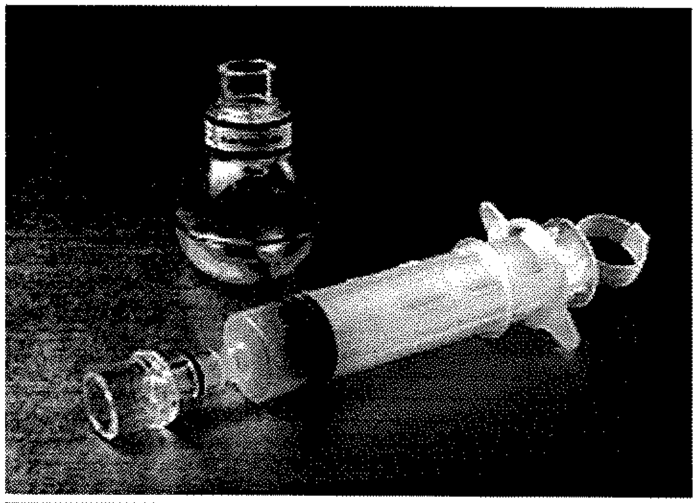


Courtesy of Airway Cam Technologies, Inc., Wayne, Pennsylvania.

SECONDARY VERIFICATION OF ET TUBE PLACEMENT

Over the years, techniques such as chest radiography, auscultation and observation of the chest and epigastrium, observation for "misting," and esophageal detection devices (EDDs) have been used to confirm ET tube placement. Although these techniques are helpful, especially when used in conjunction with $EtCO_2$ devices, there are significant limitations for neonates.[9,10,13–18] In animal and human models, even continuous pulse oximetry cannot detect esophageal intubation with acceptable accuracy.[17,19] "Although

FIGURE 2 ■ EID Esophageal Intubation Detector.



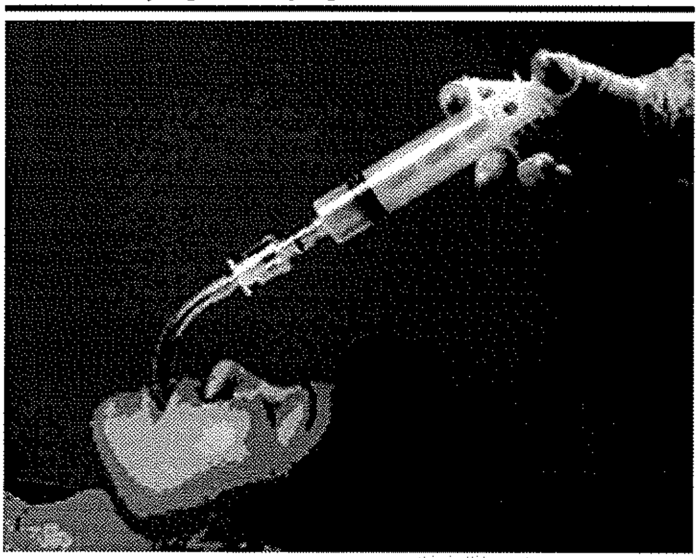
Courtesy of Wolfe Tory Medical, Inc., Salt Lake City, Utah.

unrecognized esophageal intubation ultimately leads to severe decreases in arterial oxygen saturation (SaO_2), minutes may lapse before this happens. In the American Society of Anesthesiologists closed claims project, detection of esophageal intubation required 5 minutes or more in 97 percent of cases" (p. 814).[9]

ESOPHAGEAL DETECTION DEVICE

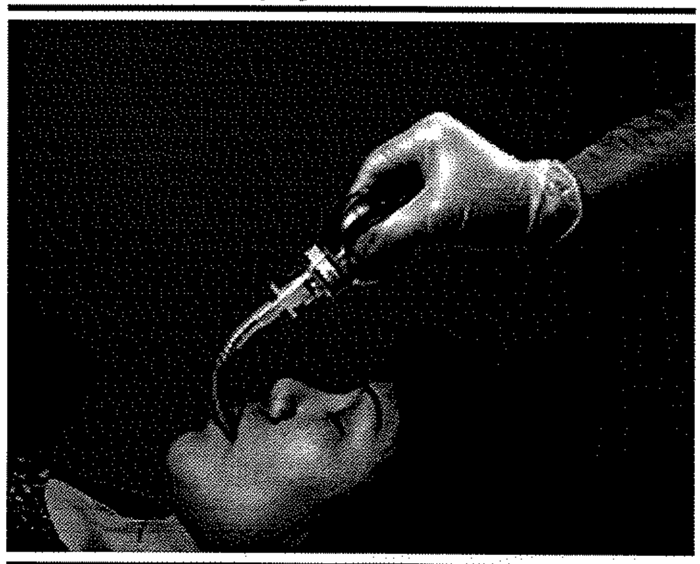
This "turkey baster" bulb or syringe device is placed onto the ET tube and then either an attempt is made to aspirate at least 20 ml of air into the syringe or one watches to see if the bulb reinflates on its own. The cartilaginous rings of the

FIGURE 3 ■ Syringe EID Esophageal Intubation Detector.



Courtesy of Wolfe Tory Medical, Inc., Salt Lake City, Utah.

FIGURE 4 ■ Bulb EID Esophageal Intubation Detector.



Courtesy of Wolfe Tory Medical, Inc., Salt Lake City, Utah.

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TABLE 1 ■ **Studies of $EtCO_2$ Detection Devices**

Source/Reference	Summary	Number of Patients/ Intubations	Age Range	Weight Range	Results
Vaghadia H, Jenkins L, and Ford R. 1989.[17]	Compared O_2 saturation, capnography, and clinical examination for recognition of esophageal intubation	20 rats	N/A	Mean weight = 257 gm	Capnography most specific for esophageal intubation O_2 saturation least specific for esophageal intubation 43% of rats did not desaturate below 85% despite 3 minutes of esophageal intubation
Higgins D. 1990.[34]	Easy-Cap use in the OR with a difficult airway infant	1 infant	2 days old	1.7 kg	Correctly identified tracheal tube placement in a neonate
Hillier S, et al. 1990.[37]	Capnometry on ventilated patients	37 intubated patients	Newborn to 6 years old	1.3–24.5 kg (mean weight = 9.7 kg)	Capnometry accurately estimates $PaCO_2$ on mechanically ventilated neonatal and pediatric patients
McEvedy B, et al. 1990.[41]	Neonatal distal and mainstream capnometry in the OR	21 intubations in 20 patients	Mean age = 36 weeks gestation	Mean weight = 2.4 kg	Both techniques accurately estimate $PaCO_2$ in critically ill neonates with respiratory failure or heart disease
McEvedy B, et al. 1990.[41]	Neonatal distal and mainstream capnometry in the OR	21 intubations in 20 patients	Mean age = 36 weeks gestation	Mean weight = 2.4 kg	Both techniques accurately estimate $PaCO_2$ in critically ill neonates with respiratory failure or heart disease
Bhende M, Thompson A, and Howland D. 1991.[32]	Easy-Cap use for verification of ET tube placement	54 intubations in 11 piglets	N/A	2.1–3.1 kg	Easy-Cap correctly identified all tracheal and esophageal intubations
Bhende M, Thompson A, and Orr R. 1992.[27]	Easy-Cap during pediatric transport for verification of ET tube placement	59 intubations in 58 patients	1 day–12 years (38% were <1 year old)	0.9–26 kg (57% were <5 kg)	Correctly identified 57 of 58 (98%) tracheal and the 1 esophageal intubation 1 false negative result (no color change) (900 gm severely hypocarbic neonate) Helped avoid unnecessary extubation in an infant with poor saturations but (+) $EtCO_2$
Bhende M, and Thompson A. 1995.[31]	Use of Easy-Cap during pediatric CPR	48 intubations in 40 infants (in full cardio-pulmonary arrest)	1 week–10 years (mean = 27 months) (25 of 40 were <1 year old)	2.5–40 kg (31 of 40 were <15 kg) (mean weight = 11 kg)	100% detection of esophageal placement during CPR using Easy-Cap 84% detection of tracheal placement during CPR using Easy-Cap
Bhende M, et al. 1995.[36]	Evaluation of a capnometer during transport	53 intubations in 50 patients	1 day–19 years (median = 1 year)	1.6–70 kg (median weight = 10 kg)	Correctly verified 100% of esophageal intubations and 96% of tracheal intubations (2 equipment failures)

(continued on next page)

trachea typically prevent the trachea from collapsing onto itself. Therefore, if the ET tube is in the trachea, the trachea will maintain its structural integrity, and, if the tube is in the trachea, air will pass into the device. With an esophageal intubation, the lack of supporting structures for the esophagus causes the esophagus to collapse during aspiration, and air will not enter the EDD (Figures 2–4).[9]

These devices may be useful in dark and noisy environments where visualization of colorimetric devices and auscultation may be difficult. They can be especially helpful in patients with very poor perfusion or those in cardiopulmonary arrest. However, outside of the NICU environment, EDDs may give misleading results in patients with morbid obesity, late pregnancy, status asthmaticus, or copious tracheal

TABLE 1 ■ Studies of $EtCO_2$ Detection Devices (continued)

Source/Reference	Summary	Number of Patients/ Intubations	Age Range	Weight Range	Results
Roberts W, et al. 1995.[4]	Comparison of capnography and other techniques for recognition of esophageal intubation in the NICU	100 intubations in 55 patients	24–32 weeks gestation	Mean weight = 1,419 gm	3.7 seconds (mean) to verify esophageal placement with capnography 76 seconds (mean) to verify esophageal placement by exam 41 minutes until CXR was able to be viewed after intubation Only 10% of esophageal intubations diagnosed by exam alone 8.3% of ET tubes wrongly removed based on exam 3 displaced ET tubes (after taping) found by capnography Successful for 54 of 55 patients (1 failure was infant with congenital heart disease, O_2 saturation <70%, and $EtCO_2$ <10 mmHg)
Poirier MP, et al. 1998.[19]	Comparison of capnography, pulse oximetry, and vital signs for detection of esophageal intubation	5 minipigs	N/A	Mean weight = 11.8 kg	7 seconds to detect esophageal tube placement with capnography No change in heart rate, O_2 saturation, or systolic blood pressure despite 3 minutes of esophageal tube placement
Aziz H, Martin J, and Moore J. 1999.[2]	Use of Pedi-Cap for detection of esophageal intubation in the delivery room and NICU	45 infants	23–41 weeks gestation	470–4,620 gm (42% were <1 kg)	100% detection of the 12 (27%) esophageal placements Esophageal detection Pedi-Cap took 8 seconds vs 40 seconds with clinical examination 30 of 33 (91%) tracheal intubations detected (3 false negatives with severely depressed Apgar scores or in arrest)
Gonzalez del Rey J, Poirier M, and Digiulio G. 2000.[42]	Capno-Flo bag vs capnography evaluation of extubation and obstruction	5 swine	N/A	Mean weight = 11.8 kg	Capno-Flo detected complete obstruction in 9 seconds Capno-Flo detected extubation in 10 seconds Bag was comparable to midstream and side-stream capnography Capno-Flo was significantly faster than capnography for detecting extubation
Repetto J, et al. 2001.[3]	Use of capnography in the delivery room for detection of esophageal intubation	27 intubations in 16 infants	23–34 weeks gestation	575–2,040 gm (44% were <1,000 gm)	Capnography identified all tracheal and esophageal intubations Esophageal detection with capnography took 10 seconds vs 46 seconds with clinical examination

(continued on next page)

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Singh S, et al. 2001.[38]	Evaluation of a portable microstream capnometer with critically ill children	20 intubated patients	Not stated	Not stated	NPB-75 portable microstream capnometer functioned as well as a stationary mainstream capnometer on PICU patients
Bhende M, and Allen W. 2002.[29]	Use of Capno-Flo bag during transport for immediate and ongoing ET tube verification	39 intubations in 38 patients	1 day–19 years (mean age = 13 months)	900 gm–80 kg (median weight = 11 kg)	Correctly identified 100% of initial tracheal and esophageal intubations Not helpful during transport for continued verification of placement

Key: Capno-Flo=Capno-Flo resuscitation bag (Nellcor); CPR=cardiopulmonary resuscitation; CXR=chest x-ray; $EtCO_2$=end-tidal carbon dioxide; Easy-Cap=Easy-Cap colorimetric device (Nellcor); NICU=neonatal intensive care unit; OR=operating room; Pedi-Cap=Pedi-Cap colorimetric device (Nellcor); PICU=pediatric intensive care unit.

secretions. And although EDDs have been useful for adults and children, equipment limitations make them unreliable in neonates and infants, and their routine use cannot currently be recommended.[9,14–16,18]

ETCO₂ DETECTION

End-tidal CO_2 detection and monitoring devices have been used by anesthesia caregivers for over 15 years and are highly recommended by anesthesiologists and by emergency medicine, pediatric critical care, and neonatal physicians alike.[3,20–24] If $EtCO_2$ monitoring is a standard among anesthesiologists who perform intubations daily, it would seem reasonable to use it to verify ET tube placement where intubations are performed less frequently and in less favorable settings. The new Pediatric Advanced Life Support guidelines recommend that all intubations be confirmed by $EtCO_2$ measurement, and the American Academy of Pediatrics Neonatal Resuscitation Program (NRP) guidelines also suggest the use of $EtCO_2$ detection devices to confirm successful endotracheal intubation.[12,13] Table 1 provides an overview of the literature addressing $EtCO_2$ monitoring and capnography as methods to assess ET tube placement.

ETCO₂ MONITORING

Carbon dioxide (CO_2), a by-product of cellular metabolism, is transported in the venous blood to the lungs, where it is eliminated during the expiratory phase of breathing. End-tidal CO_2 is the amount of CO_2 present at the end of exhalation. Significant amounts of CO_2 are present only during expiration, and the normal range for $EtCO_2$ is 35–45 mmHg.[25] Monitoring the $EtCO_2$ therefore indicates the adequacy of ventilation, perfusion, and gas exchange in the lungs.[5]

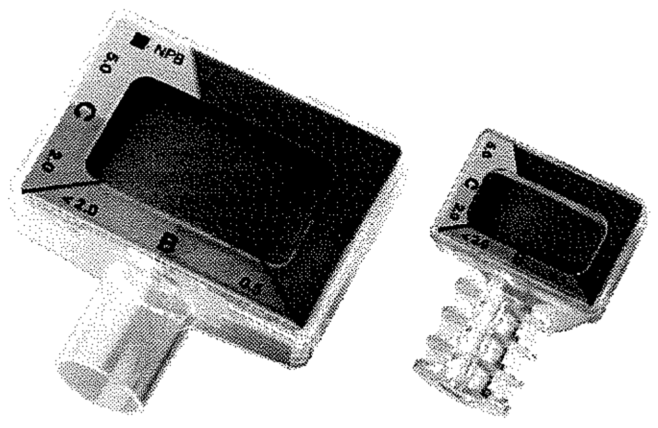
Currently available $EtCO_2$ monitoring devices fall into three categories: colorimetric (changes indicated by color display), capnometric (numeric display), or capnographic (numeric with waveform display). Because colorimetric devices are among the most commonly used devices in prehospital, transport, and emergency medicine, we focus primarily on $EtCO_2$ detection based on the use of colorimetric devices as suggested in the NRP guidelines.[12]

Colorimetric $EtCO_2$ Detection Devices

> Since the lungs are the primary organ for retrieval of CO_2 from the body, CO_2 levels will be much higher in the trachea than elsewhere in the body. Therefore, detection of the presence of CO_2 in the endotracheal tube can serve as confirmatory evidence that the tube is in the trachea rather than the esophagus.... If you have any doubt about correct placement of the endotracheal tube, connect a CO_2 detector and note the presence or absence of CO_2 during exhalation. If CO_2 is not detected, consider removing the tube, resuming bag-and-mask ventilation, and repeating the intubation process [p. 5-17].[12]

In our transport, emergency department, and NICU experiences, the two types of colorimetric $EtCO_2$ detection devices most commonly used for neonates are Easy-Cap/Pedi-Cap adapters (Figure 5) and Capno-Flo

FIGURE 5 ■ Easy-Cap and Pedi-Cap $EtCO_2$ detection devices.

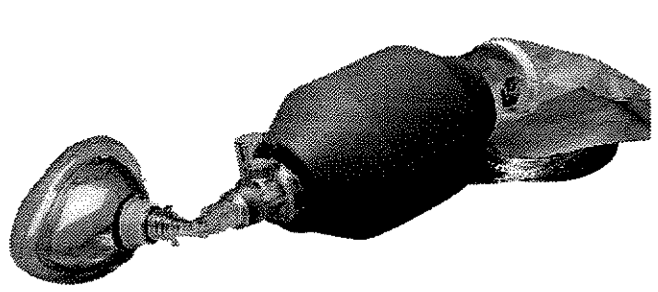


Courtesy of Nellcor Puritan Bennett, Inc., Pleasanton, California.

resuscitation bags. The Pedi-Cap, designed specifically for infants and children, is small and results in minimal additional dead space (3 ml).[26] Although Pedi-Caps are recommended for use with infants weighing more than 1 kg, published studies (and our experience) have demonstrated successful use of these devices to detect esophageal intubation in neonates much smaller than 1 kg.[2,26,27] According to the manufacturer, Easy-Caps and Pedi-Caps are accurate for 2 hours of continuous use or 24 hours of intermittent use.[26]

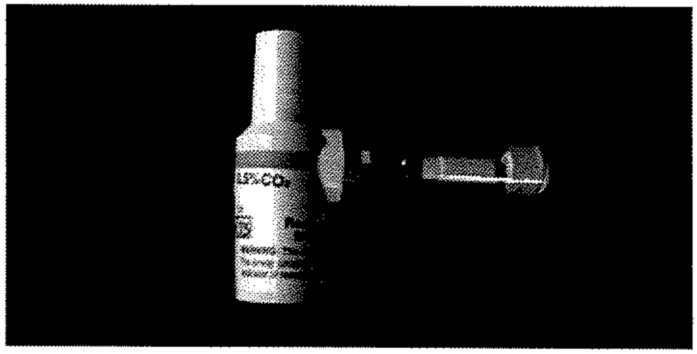
Among the most impressive features of the Easy-Cap/Pedi-Cap devices are the ease of colorimetric visual analysis and the "breath-to-breath" changes. The color changes are easy to see and remember, and there is also a numeric scale on the front of the device, facilitating use even by those who have difficulty differentiating colors.[28] If the adapter turns gold, you can feel assured that the ET tube is in the trachea (many practitioners use the mnemonic device "Gold is good" to remember this). If the adapter stays or turns purple in the presence of adequate pulmonary perfusion, the tube is probably misplaced.

FIGURE 7 ■ Capno-Flo resuscitation bag with built-in $EtCO_2$ detection device.



Courtesy of Nellcor Puritan Bennett, Inc., Pleasanton, California.

FIGURE 6 ■ Airway Circulation Evaluator $EtCO_2$ detection device.

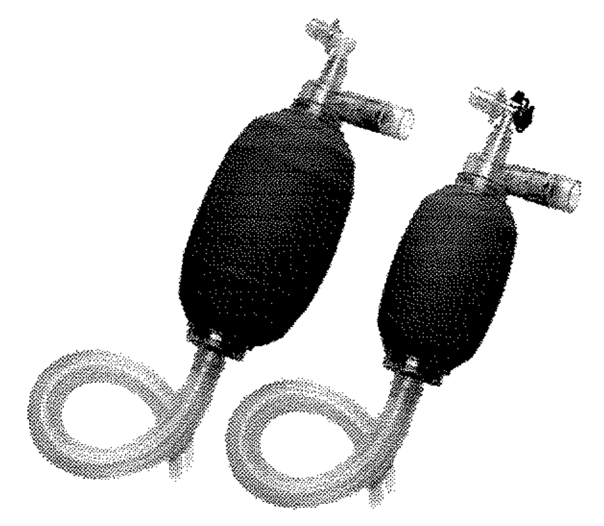


Courtesy of Ventlab, Mocksville, North Carolina.

Rapid "breath-to-breath" color changes are another feature of these devices. Once initial placement of the ET tube has been verified, ongoing assessment is possible because the color on the adapter actually changes back and forth as ventilations are provided.[25] We have experienced several occasions in which colorimetric $EtCO_2$ detection initially verified that the ET tube was in the trachea, and then immediately after the chest x-ray was taken, the adapter stopped changing from purple to gold, indicating the lack of CO_2 in the exhaled air. The breath-to-breath color change provided an early and convincing indication of the dislodgement of the ET tube even before the patient's oxygen desaturation could be detected, allowing for corrective action before dangerous arrhythmias or even cardiac arrest could occur.

One product similar to the Easy-Cap and Pedi-Cap is the Airway Circulation Evaluator (ACE) (Ventlab, Mocksville,

FIGURE 8 ■ INdGO resuscitation bag with built-in/replaceable $EtCO_2$ detector and breath-to-breath color changes.



Courtesy of Nellcor Puritan Bennett, Inc., Pleasanton, California.

North Carolina) (Figure 6). The ACE changes from white to purple in the presence of significant exhaled CO_2. Another product is the Capno-Flo resuscitation bag, which has a built-in $EtCO_2$ detector (Figure 7). This configuration ensures that the detector is attached and available to use during manual ventilation. The biggest drawback of the currently available Capno-Flo resuscitation bag is that, unlike the Easy-Cap and Pedi-Cap, it does not produce true "breath-to-breath" color changes. If the ET tube is dislodged or if perfusion ceases, the color change back to purple may not be noted until after as many as six breaths.[26,29] The manufacturer of the Capno-Flo resuscitation bag has recently introduced a "next-generation" resuscitation bag, called INdGO, that is designed to address this concern by providing breath-to-breath color changes (Figure 8). This bag also provides a solution to the problem of potential contamination, such as mucus, blood, or meconium, affecting the detector: A built-in/replaceable, CO_2 detector is out of the direct path of potential contaminants and involves no additional dead space. Currently available in pediatric and adult sizes, the INdGO line is expected to introduce an infant model in the future.[26]

Limitations of Neonatal Colorimetric $EtCO_2$ Detection Devices

> [T]he physiologic adaptation to extrauterine life during the immediate neonatal period is unique. The neonate has to increase pulmonary blood flow from 7 percent to 100 percent of the cardiac output and expand fluid-filled, collapsed lungs in order to exchange gas [p. 286].[3]

Despite the obvious benefits of using $EtCO_2$ detection devices in neonates, their unique physiology and stages of transition result in some limitations.

Decreased Peripheral Perfusion. $EtCO_2$ detectors are extremely reliable as long as the patient has a perfusing cardiac rhythm. In conditions of little or no perfusion, however, the accuracy of the device is not quite as good because very little CO_2 gets to the lungs to be exhaled. Even with the ET tube correctly placed, the adapter may not change colors as quickly, if at all.[12,13,30,31] In neonates, especially those who are very premature or with very low birth weight, poor cardiac output, complex congenital heart disease, or cardiac arrest, the amount of exhaled CO_2 may not be sufficient to be reliably detected by colorimetric CO_2 detectors.[2,3,12,31,32] More studies are needed to determine the accuracy and usefulness of $EtCO_2$ detection devices in these critically ill patients.

False Positive Readings. Another concern is that false positive color changes can occur even if the ET tube is not in the trachea. To protect against this, the manufacturers of colorimetric devices recommend checking the detector to verify ET tube position after it has been in place for six breaths. These initial breaths allow any CO_2 that might be in the stomach to be dispersed and the true color reading to be verified.[26]

A false positive reading is also possible if the ET tube is placed in the hypopharynx. In this position, a color change may be detected even though ventilations are entering both the esophagus and trachea.[10,22] A way to avoid this situation is to remember that one can estimate the proper placement depth of an ET tube from the size of the infant. For most infants, the placement of the "lip line" should be 6 cm plus the infant's weight in kilograms. For example, a 4 kg infant's ET tube should be taped at the 10 cm line ($6 + 4 = 10$).[33] Chest radiographs can confirm the correct depth of the secured ET tube once proper placement in the trachea has been verified.[1,4,10]

Detector Contamination. Another concern is that the detector may be contaminated by any of the fluids found in and around the respiratory tract. The currently available adapters are placed directly between the resuscitation bag and the ET tube; therefore, emesis, blood, pulmonary secretions, and other fluids could easily contaminate the detector. After the adapter has been exposed to fluids, it must be replaced. In addition, because of the physical effects on the colorimetric strip, administration of medications such as epinephrine, atropine, and lidocaine via the ET tube can severely limit the device's ability to demonstrate a color change.[25,34,35]

Limited Time Accuracy. Finally, there are limitations of time and usage. Adequate exhalation time is needed so that the detector can actually change colors. Again, this may take up to six ventilations with a resuscitation bag.[26] These detectors can work very well for the initial verification of ET tube placement and for the next two hours. However, after two hours of continuous usage, per the manufacturer, the detector in use is no longer considered reliable and should be replaced with a new one.

Numeric Capnometry

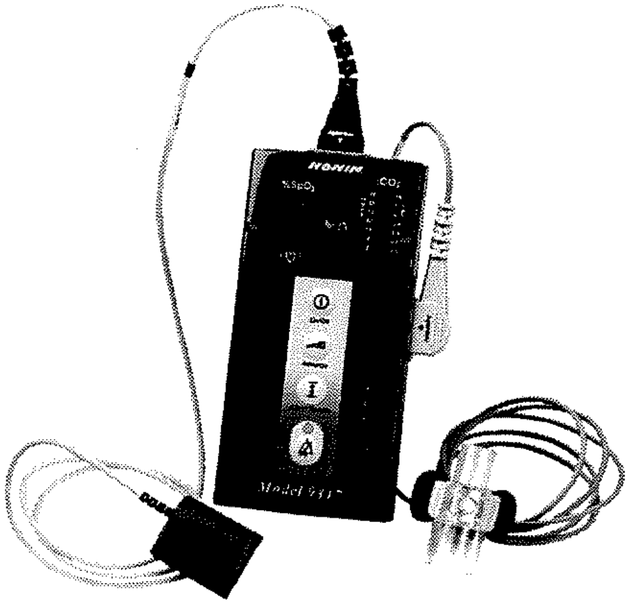
This technique involves using an electronic device that is placed directly on the ET tube to take a quantitative measurement of exhaled CO_2 (Figure 9). Normal $EtCO_2$ values are 30–43 mmHg. Numeric capnometers can be very helpful in the initial verification of ET placement and in the ongoing assessment of respiratory status. Potential concerns, however, include the need to remember ranges of numbers, as opposed to simply observing color changes, and the initial expense of purchasing these electronic monitors. As with colorimetric devices, exposure to fluids can significantly interfere with the usefulness of the equipment.[13,36–38]

Capnography

> Although carbon dioxide waveforms are observed in one third of esophageal intubations, repeated ventilation results in a rapidly diminishing carbon dioxide

Switch photo positions

FIGURE 9 ■ Capnometer for measuring $EtCO_2$; also measures heart rate and SaO_2.



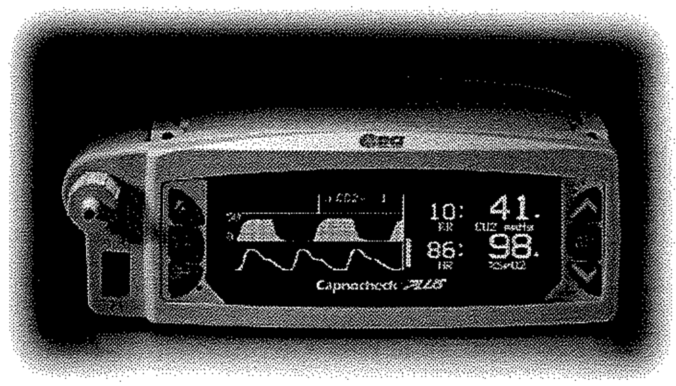
Courtesy of Nonin Medical, Inc., Plymouth, Minnesota.

> level.... As a result of the dilution with successive ventilation, it is unlikely that any carbon dioxide would be detected after the sixth breath, making it easy to distinguish esophageal from tracheal intubation [p. 814].[9]

FIGURE 10 ■ Capnography available with Nellcor Oximax NPB-75.

Courtesy of Nellcor Puritan Bennett, Inc., Pleasanton, California.

FIGURE 11 ■ Capnocheck Plus.



Courtesy of BCI, Inc., Waukesha, Wisconsin.

Capnography is the numeric and graphic display of the measurement of carbon dioxide. In anesthesia, critical care, transport, and many NICUs, capnography is quickly becoming the $EtCO_2$ monitoring technique of choice.[3,4,9,21,22,39] Unlike colorimetric devices which are used for initial or intermittent monitoring, capnography not only provides verification of ET tube placement, but also provides continuous numeric and waveform indicators (Figures 10 and 11). With these capabilities, capnography can greatly reduce the number of unidentified misplaced ET tubes and provide quick and reliable evidence of ET tube dislodgement, displacement, or obstruction. In addition, the ability to accurately assess CO_2 levels may provide valuable information about the patient's cardiopulmonary status and his response to resuscitation and treatment. Capnography can also be valuable in determining the patient's response to ventilator changes, weaning attempts, and the depth of neuromuscular blockade. In addition, it may decrease the number of arterial blood gas tests needed.[4,23,39]

SUMMARY

> The importance of verifying endotracheal tube placement cannot be overemphasized, since unrecognized esophageal placement is rapidly fatal.... It is important to note that although esophageal intubation is undesirable, it is not harmful if quickly recognized [p. 51].[40]

$EtCO_2$ monitoring for both initial and ongoing verification of ET tube placement is crucial. Capnography with numeric and waveform analysis can be a great addition to the armamentarium of transport, emergency, and NICU staff. As recommended by various specialty groups, we should be routinely utilizing $EtCO_2$ detectors to ensure that the ET tube starts and stays in the right place for all of our patients.

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