# Emerging Uses of Capnometry in Emergency Medicine

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## The Physiologic Basis for Capnometry

Capnometry is based on a discovery by chemist Joseph Black, who in 1875 noted the properties of a gas released during exhalation that he called "fixed air." That gas—carbon dioxide—is produced as a consequence of cellular metabolism, a waste product of the process of oxygen and glucose combining to produce energy. Carbon dioxide exits the body via the lungs. The amount of $CO_2$ in exhaled breath reflects cardiac output and pulmonary blood flow as the gas is transported by the venous system to the right side of the heart and then pumped into the lungs by the right ventricle. Carbon dioxide is involved not only in oxidative cellular metabolism, but also in gas transport and ventilation. Capnometers measure the concentration of $CO_2$ exhaled at the end of the breath, commonly known as the end-tidal breath $CO_2$ ($ETCO_2$). When outside the normal range, high or low, it indicates a problem with ventilation that requires immediate action. As long as the heart is beating and blood is flowing, $CO_2$ is delivered continuously to the lungs for exhalation. Anything that interferes with normal ventilation quickly changes $ETCO_2$, even as $SPO_2$—the indirect measurement of oxygen saturation in the blood—levels remain high. Thus, $CO_2$ is a better, more sensitive and more rapid indicator of ventilation problems than $SPO_2$ measurements.[1]

## Why ETCO2 Monitoring is Important

Capnometry can be a life saving modality, because changes in $ETCO_2$ levels are an early indicator of several potentially dangerous conditions. A sudden decrease can indicate, for example, hyperventilation or impending shock; a sudden increase can indicate malignant hyperthermia even in the absence of changes in breathing. The absence of $ETCO_2$ in an intubated patient is an indicator of a misplaced endotracheal tube, a life-threatening situation. Too much or too little exhaled $CO_2$ not only foreshadows deleterious physiological trends in critically ill or injured patients but abnormal blood $CO_2$ in itself it can have serious consequences. It is generally accepted that $CO_2$ monitoring is the practice standard for determining whether endotracheal tubes are correctly placed. However, there are other important indications for its use as well. Ventilatory monitoring by $ETCO_2$ measurement has long been a standard in the surgery and intensive care patient populations. Carbon dioxide monitoring should be regarded in the pre-hospital setting like it is in the surgical suite: as a vital sign of a patient's ventilatory status, helping to guide immediate and future treatment. Emergency Medical Services (EMS) organizations understand the importance of monitoring ventilation in addition to oxygenation in the critically ill or injured patient and have begun incorporating protocols that include this vital parameter. Yet, the applications of $CO_2$ monitoring in this setting have been limited despite data demonstrating its value.[2] That $CO_2$ monitoring is not as widely utilized as it could be in pre-hospital medicine is an issue that deserves new consideration.[3]

## Where is CO2 Monitoring Underutilized?

Thousands of patients are intubated or given bag-valve-mask (BVM) ventilation every year in the pre-hospital setting. In contrast to the controlled environment of the operating room or the ICU, the circumstances in which EMS personnel treat patients are unique. Patients are often in a high-motion, physically challenging environment in which monitoring equipment can malfunction and in which large, bulky devices are impractical. Yet, proper support and monitoring of ventilation are critical for successful outcome in these seriously ill patients. Oxygen saturation, or $SPO_2$, can be measured as an indicator of ventilation, but haemoglobin oxygen saturation is not as rapidly sensitive to changes in ventilatory status as $ETCO_2$. Further, studies in ambulance settings have demonstrated that hypothermia and vasoconstriction might impair the ability of oximeter sensors to detect changes in $SPO_2$ even in the presence of respiratory distress. Capnometry in the emergency setting can provide the data needed to monitor and correctly adjust ventilation parameters much more quickly and sensitively.

The most common reason in the pre-hospital emergency setting to use capnometry is to ensure that endotracheal tubes are correctly placed, an important problem in an out-of-hospital setting. One study showed that unrecognized oesophageal intubation is as high as 25%.[4.] Another study showed unrecognized endotracheal tube misplacement is present in 3% of cardiac arrest patients and in 17% of trauma patients transported to a Level 1 trauma centre. It can be argued that even patients who are not intubated but are receiving BVM , should also have their $CO_2$ levels monitored. Although they are not subject to the potential disaster of a misplaced endotracheal tube, they are vulnerable to the consequences of over- or under ventilation. In addition, tracking the $ETCO_2$ concentration of an artificially-ventilated patient has predictive value in determining the efficacy of CPR.[5,6,7,8] The use of capnometry could prevent serious problems in pre-hospital patient management as well assist in triage after the patient arrives in the hospital emergency department, but it is not universally employed. One EMS director in a large U.S. city estimates that only 75% of EMS systems have some form of $ETCO_2$ monitoring, meaning that 25% do not.[9] A 2005 study in Germany showed that capnometers were available to only 66% of emergency medical personnel,[10] and while this percentage has likely grown in the last several years, $ETCO_2$ monitoring is far from universal in EMS systems.

## Current Methods of Measuring ETCO2

There are three technologies currently available for $CO_2$ monitoring: colorimetric devices, cable-connected mainstream, sidestream, and self-contained mainstream. This last category is the newest entry in the armamentarium of available devices. Mainstream or sidestream devices can either display $CO_2$ as a digital readout (capnometer) or as a waveform (capnograph).

*Colorimetric devices* detect and present a range of $ETCO_2$ in a qualitative format rather than as a specific number. They display colour changes indicative of the presence of $CO_2$. This type of device has a pH-sensitive chemical indicator visible through a clear dome that turns from purple to yellow when attached to a correctly intubated patient, indicating that $CO_2$ is in the expired breath and the tube is therefore in the trachea. If it is attached to a patient with the tube in the oesophagus, it remains purple. While it is easy to use, it can give false positive readings caused by the presence of $CO_2$ in the oesophagus, from carbonated beverages ingested by patients just prior to application, or if certain gastric contents or drugs are present.[11] In addition, its sensitivity is markedly reduced in patients with cardiac arrest and low perfusion,[12] up to an incidence of 13% failure rate.[13] Finally, colorimetric indicators require six breaths before they can give an accurate reading. Colorimetric devices are placed on ambulances in the intubation airway bag and are used by ALS-trained personnel whenever an intubation is required. They are also widely available in hospital crash carts because of their ease of use and convenience. However, due to their unreliability, some countries in Europe have prohibited their use in both pre-hospital and hospital settings.[14]

*Cable-connected mainstream or sidestream* monitors measure $CO_2$ using a sensor having a source of infrared light, a chamber containing the gas sample, and a photo detector. When the expired $CO_2$ passes between the beam of infrared light and the photo detector, the light absorption is proportional to the concentration of $CO_2$ in the gas sample. The photo detector response is calibrated with known concentrations of $CO_2$ and stored in the monitor's memory. In sidestream designs, a portion of the patient's expired gases is transported from the airway through a sampling tube to the sensor. Measuring the concentration of a gas distant from the sampling site is however problematic, since the condition under which the sample is taken is subject to varying water content, humidity, pressure and temperature. Mainstream designs have by contrast the source of infrared light and the photo detector located right at the airway. This arrangement results in an immediate measurement without delays and a precise CO2 waveform.

Cable-based sidestream/mainstream $CO_2$ measurement is an optional feature in defibrillators or "all in one" patient monitors utilized by ALS-trained paramedics, accomplished by the addition of a sensor added to others such as ECG, $SPO_2$, and non-invasive blood pressure. The $CO_2$ information is registered and displayed on the screen of the device.

The most recent innovation in $ETCO_2$ monitoring technology is a hand-held, battery-powered *self-contained mainstream* device called EMMA (PHASEIN AB, Sweden). The EMMA monitor detects $ETCO_2$ values in every breath while also showing the respiratory rate. EMMA is very lightweight, weighing only about 60 grams and requires no calibration. It operates on two standard AAA batteries, and takes less than a second to register accurate measurements, which are shown on an LED display.

Both cable-connected mainstream or sidestream devices and self-contained mainstream devices provide quantitative displays of $ETCO_2$. The results can be displayed as continuously varying digital readouts or a continuous waveform.

Different from colorimetric devices, *quantitative capnometers* display true readings of carbon dioxide usually expressed as a partial pressure of $CO_2$ in units of mmHg having a normal value between 35-45 mmHg. The use of quantitative capnometers is an advantage in pre-hospital medicine because it allows fast and reliable insight into ventilation, circulation, and metabolism. The availability of this technology may allow the wider use of capnometry in EMS because of its ease of use and cost effectiveness. It could also lead to an expansion of applications within the emergency medicine spectrum that are not common now but should be considered as the value of $CO_2$ monitoring is recognized well beyond its standard application as an endotracheal tube placement verifier. *Capnography* refers to the continuous, trend and real-time $CO_2$ waveform display. These tracings have recognizable patterns that are helpful to advanced analysis of respiration, ventilation, and perfusion. Capnography is regarded as the ultimate form of $CO_2$ monitoring, includes a number of important parameters, and can be helpful in the differential diagnoses of a number of serious conditions. The wide availability of $CO_2$ monitoring devices suggests that there is no technological impediment to its wider use. Some of the newer uses of capnometry are evolving as its importance in the critically ill and injured patient are being recognized.

## Emerging Uses of Capnometry in Pre-hospital Medicine

### ETCO2 monitoring during bag-valve-mask ventilation

Bag-valve-mask ventilation (BVM) is one of the most common methods of ventilating patients during cardiac arrest, respiratory arrest, and trauma, and a frequently used procedure for those trained in Basic Life Support (BLS) since they are not certified to use devices that invade the airway. While other technologies may appear to have superseded it, there are clinicians who assert that BVM is at least as effective in ventilating patients as endotracheal intubation as demonstrated by survival rates. In fact, a large study concluded that the latter leads to longer pre-hospital times.[15] However, BVM is thought to be a difficult procedure to perform, sometimes requiring two operators who must remain focused on maintaining a seal on the patient's mouth while delivering ventilation. Studies have shown that varying BVM skill levels among EMS providers have led to poor patient outcomes.[16,17] The use of capnometry could improve these outcomes by providing real time continuous feedback about adequacy of ventilation. However, the segmentation of levels of pre-hospital emergency care that EMS personnel are certified to provide has limited its use by more basic-level providers. In the United States, the levels consist of (1) Medical First Responder, (2) Emergency Medical Technician-Basic (EMT-B), (3) Emergency Medical Technician Intermediate (EMT-I), and Emergency Medical Technician-Paramedic (EMT-P). The last two categories, comprising over 200,000 EMTs as of 2006,[18] of whom 25% are paramedics, are trained in Advanced Life Support (ALS), which includes the use of capnometry. Levels 1 and 2—First Responders and EMT-Basic operate advanced medical devices such as bag mask resuscitators, facial masks, oxygen equipment and monitors, ventilators, and most recently, the automated external defibrillator (AED). They would be able to use portable mainstream monitors with little training but are not currently certified to do so.

### ETCO2 monitoring during transport both to and within the hospital

Several published studies have documented the importance of $CO_2$ monitoring of critically ill or injured patients during transport,[19,20,21] whether from the ambulance or helicopter to the emergency department, or from the emergency department to other areas of the hospital. These patients are generally intubated and some are on mechanical ventilators. Both pediatric and adult advanced life support guidelines require $ETCO_2$ monitoring during transport.[22] A sudden change in $CO_2$ levels could indicate serious conditions such as endotracheal tube displacement, malfunction of the mechanical ventilator, or loss of pulmonary blood flow. However, even non-intubated patients could benefit from $CO_2$ monitoring, perhaps being an even more vulnerable population since they do not have an endotracheal tube in place and are subject to rapid changes in respiratory status. In two studies, capnometry provided more reliable data than oximetry on patients during transport,[23,1] leading the authors to recommend the use of $CO_2$ monitoring for victims of even minor trauma during transport to the emergency department. Often portability is a factor in the choice of capnometers, especially when patients are connected to other space-occupying monitors. In some cases, time to transport patients for in-hospital treatment is a factor and thus a reliable, portable device that does not need calibration is an advantage.

### ETCO2 monitoring to guide ventilation parameters

Much has been published about the importance of monitoring ventilation to avoid hyperventilation in particular. It is well recognized that hyperventilation is harmful to patient outcomes, yet it continues to be seen in the pre-hospital setting. Excessive ventilation rates result in significantly increased intrathoracic pressure and decreased coronary perfusion pressures and survival rates.[24, 25] The goals for patients receiving artificial ventilation are controlled ventilation, optimized inspiratory time, and airflow.[26] The problem of hyperventilation is particularly relevant in patients with severe head-injuries in whom its negative effects have been intensively studied.

In fact, the use of pre-hospital intubation has been challenged on the grounds that it predisposes to hyperventilation.[27] Careful monitoring of $CO_2$ and respiratory rate is required for the prevention of hyperventilation and is paramount to achieving improved outcomes in the field.[28] Hyperventilation is an issue as well with the use of paramedic rapid sequence intubation (RSI) in patients with severe head-injuries. There are mixed reports on whether or not RSI protocols increase intubation success in patients who cannot be easily intubated without the use of medications.[29,30.] Two San Diego studies were conducted to look specifically at the traumatic brain injury population in whom the risks of hyperventilation are well known. The first was a multi-agency ground transport study designed to explore the impact of hypoxia and hyperventilation on outcome. One of the study participants used portable digital $CO_2$ monitors with ventilation parameters modified to target $ETCO_2$ values of 30 to 35 mmHg. Patients in the $ETCO_2$ monitored group had a lower incidence of inadvertent severe hyperventilation than those without $ETCO_2$ monitoring; those who were monitored also had a reduced mortality rate. The authors concluded that the use of $ETCO_2$ monitoring is associated with decreased inadvertent severe hyperventilation and those patients who were not hyperventilated had a lower incidence of mortality.[31]

The second study was conducted in an air medical transport setting. It showed a different outcome: patient clinical parameters improved with paramedic RSI. There was a statistically significant decrease in patient mortality with air transport compared with the ground transport. Air medical crews used capnometry to guide ventilation on all study patients. The authors concluded that better outcomes may be attributed to the use of capnometry to guide ventilation.[32]

### *Spot checking ETCO2 throughout the spectrum of emergency care*

Another application of capnometry is to spot check $ETCO_2$ levels and respiratory rates in patients as they progress through the emergency management system. Spot checking cannot practically be performed by equipment requiring time consuming set up or calibration. With a portable capnometer connected to a properly sealed face mask, any EMT or First Responder could ascertain $ETCO_2$ and respiratory rate in only two breaths. The results of spot checking could suggest a change in medical management or verify that current procedures are working.

### *ETCO2 monitoring during emergency department delays*

Because of the overcrowding of emergency departments especially during multiple trauma incidents, patients in the emergency department may experience delays until the appropriate specialists can be found to decide upon diagnosis and/or treatment. In such cases, fundamental to the appropriate care of these patients is the use of monitoring devices to ensure that patients remain stable until definitive treatment. In addition to monitoring of oxygenation, cardiac output, arterial perfusion pressure, intravascular volume, and markers of tissue hypoxia, ventilation should be monitored via capnometry as well.[33]

### *ETCO2 monitoring for assessment of the efficacy of CPR and for prediction of survivability*

A number of animal and human studies have shown an excellent correlation between $ETCO_2$ and cardiac output during cardiopulmonary resuscitation and during states of low blood flow,[34] making capnometry an effective tool to assist in evaluating the efficacy of cardiopulmonary resuscitation efforts. Reductions in $ETCO_2$ are associated with comparable reductions in cardiac output; increases in $ETCO_2$ are associated with return of spontaneous circulation (ROSC). The interpretation of $ETCO_2$ in the field has to take into account that controlled ventilations may be difficult or impossible when manual CPR is interrupted by patient movement or a change in rescuer position. However, several studies have concluded that certain changes in $ETCO_2$ levels are associated with successful CPR. A key study found that a rapid increase in $CO_2$ levels within 30 seconds of ROSC, followed by a decrease four minutes later that remained stable, is an almost immediate indicator of successful resuscitation.[5]
Carbon dioxide monitoring has also been used to predict out-of-hospital cardiac arrest survival. A 1985 study looked at this question in 34 patients, of who 9 survived resuscitation. These 9 patients had higher average $ETCO_2$ levels during CPR than the 25 who did not.[5] Other studies confirmed these findings via different methodologies.[34] One of them was performed in 150 consecutive victims of cardiac arrest outside the hospital who had electrical activity but no pulse. The patients were intubated and evaluated by mainstream $ETCO_2$ monitoring. The authors' hypothesis was that an $ETCO_2$ level of 10 mm Hg or less after 20 minutes of CPR would predict death. Of the 150 patients, 35 patients survived to hospital admission, and in fact, the study showed that after 20-minutes of CPR, an $ETCO_2$ value of 10 mmHg or less was predictive of death.[8] Other studies confirm the 10 mmHg threshold. One found that initial, final, maximum, minimum, and mean $ETCO_2$ values were all higher in patients who were resuscitated than in those who were not. No patient with a reading below 10 mmHg survived.[7] The data from multiple studies confirm that capnometry appears to offer an effective tool to evaluate the progress and results of cardiopulmonary resuscitation and should be more widely used for this purpose by both ALS and BLS providers.

## The Future of Capnometry in Emergency Medicine

Based on the abundance of published studies, the value of $ETCO_2$ monitoring in emergency medicine is increasingly clear. Used in the past primarily for verification of correct endotracheal tube placement, its utility in monitoring ventilation in both intubated and critically ill non-intubated patients is being recognized. It is particularly effective in patients in whom inadvertent hyperventilation can cause a secondary injury and in assessing the efficacy of cardiopulmonary resuscitation. Its value in monitoring critically ill and injured patients during transport not only by ambulances or helicopters to hospitals but also within the hospital has resulted in practice standards adopted by a number of professional organizations worldwide. The role of $ETCO_2$ monitoring is also evolving within the hospital. There is increasing evidence that it is underutilized in this setting, perhaps because its critical importance in verifying correct endotracheal tube placement has limited the recognition of its utility in other clinical circumstances. It is recognized that pulse oximetry values can remain high for a considerable time while respiratory distress remains undetected: only $ETCO_2$ monitoring will rapidly indicate impending respiratory system deterioration. Checking $ETCO_2$ levels when respiratory and ventilatory distress is suspected should be part of emergency department protocols. Spot checking $ETCO_2$ in both intubated and non-intubated patients represents another important use of capnometry, made more practical by the availability of the new portable, mainstream capnometers. Finally, making capnometry a standard for BLS providers is the next positive step in patient care. The difficulty of BVM ventilation and studies confirming poor outcomes for BLS personnel attributed to their varying skills argue for using capnometry whenever bag-valve-mask ventilation is performed. Cost is universally a consideration when the adoption of new technology is considered. Recently, advances in sensor design and miniaturization have made $ETCO_2$ monitoring more economical. Patients are often in physically inaccessible locations, time is always of the essence, and low light often make attaching monitors to patients and reading the display a challenge. Having a rugged, portable, mainstream capnometer that can give both $CO_2$ measurements and respiration rate accessible in an EMS "grab bag" is a clinical advantage.

Pre-hospital medicine is at an exciting time in its development as a specialty. Not only does it attract people whose dedication to quality patient care is superior, it is innovative in adopting new technologies from clinical areas outside EMS for its unique patient population. Capnometry, long established as essential in the surgical suite and in intensive care, is just coming into its own in pre-hospital medicine. It is clear from the data[36] that it should be more widely applied. The availability of portable, quantitative capnometers makes it cost effective and convenient to carry out in a time sensitive, geographically challenging field of medicine.

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