Proceedings of The National Conference
On Undergraduate Research (NCUR) 2019
Kennesaw State University
Kennesaw, Georgia
April 11-13, 2019

Capnography's Ability to Improve Patient Health Outcomes in the Prehospital Setting

Anuj H. Kotak
Department of Biomedical Engineering
Virginia Commonwealth University
701 West Grace Street
Richmond, Virginia 23220 USA

Faculty Advisor: Dr. Faye Prichard

Abstract

In the prehospital setting, capnography – or end-tidal CO2 (etCO2) – is primarily used to ensure the correct placement of endotracheal (ETT) tubes for ventilation by advanced life support (ALS) EMS providers. However, given that, in a few seconds, capnography measures the perfusion status of a patient, capnography's ability to improve health outcomes in the prehospital setting beyond its use for ETT placement were examined. Capnography's prehospital use in three categories were explored: for prognostic field impressions, for improving triage, and for improving EMS operations. Scholarly articles supporting capnography's prognostic value for a number of disorders were collected and their findings were systematically reviewed to ascertain capnography's practical diagnostic value. Additionally, information from previous literature that supported capnography's practical ability to improve triage and EMS operations was synthesized. Finally, the findings and analysis were summarized into a field manual and triage flowchart that would allow basic life support providers to utilize the benefits of capnography without ALS training. The research revealed that etCO2 has strong prognostic value in predicting diabetic ketoacidosis, asthma, COPD, CHF, mortality in acute trauma patients, and sepsis, at various cutoff etCO2 values. Capnography's ability to realize quick field impressions would allow EMS personnel to provide tailored care and allow receiving hospitals to prepare adequately for the patient's needs. Furthermore, it was concluded that capnography could improve triage efficiency, as it provides a rapid assessment of airway, breathing, and circulation and predicts prehospital and in-hospital mortality. Predicting mortality before time-intensive vital measurements and interventions are performed can cause more effective allocation of EMS's time in situations, such as mass-casualty incidents, where rapid triage is needed. This improves EMS response time and more resources can be allocated to high-priority patients, which positively impacts on the health outcomes of the EMS agency's community.

Keywords: Prehospital Care, etCO2, end-tidal CO2

1. Introduction

In the prehospital setting, capnography – or end-tidal CO2 ($etCO_2$) – is primarily employed by advanced life support (ALS) providers while placing an endotracheal tube (ETT) to manually ventilate a patient. However, given that, in a few seconds, capnography measures the ventilation and perfusion status of a patient, Krauss & Falk[1] have proposed that capnography can aid in the speedy diagnosis and treatment of a wide variety of respiratory and metabolic conditions in both the hospital and prehospital settings. Additionally, in the prehospital setting, basic emergency medical technicians (EMT-B) are not certified to perform invasive procedures. However, the non-invasive nature of capnography monitors coupled with their quick measurement time may make them valuable tools to EMT-Bs, and AEMTs as well. Although capnography is currently utilized primarily for ETT placement, capnography can improve patient health outcomes in the prehospital setting through its improvement of prognostic field impressions, triage, and EMS operations, though additional research is required to determine cutoff $etCO_2$ values for prognosis and mitigate limitations of capnography caused by drugs and consumption of certain foods.

In order to understand capnography's potential for improving prognosis, triage, and operations in the prehospital setting, it is necessary to understand capnography's terminology, normal pathophysiology, and currently accepted uses. Capnography is the measurement of the concentration of CO2 (pCO2), measured in mmHg, exhaled by a patient with each breath. Capnography can be reported as a graph of pCO2 vs time, known as a CO2 waveform or capnogram (see Figure 1). The peak CO2 concentration on a capnogram, seen at the end of each tidal breath, is known as end-tidal CO_2 ($etCO_2$). A normal capnogram shows a characteristic trapezoid (shown in Figure 1) and a normal $etCO_2$ ranges from 35 to 45 mmHg, according to Krauss & Falk[1]. Capnography provides an assessment of ventilation and perfusion. Changes in the shape and features of a capnogram are indicative of abnormalities in the rate and adequacy of breathing[1]. Similarly, $etCO_2$ values indicate the quality of ventilation, but can also provide a comprehensive view of a patient's general perfusion as it estimates the arterial blood CO_2 ($PaCO_2$), according to Kerslake[2].

Capnography monitors measure exhaled CO_2 through one of two mechanisms: mainstream and sidestream. Mainstream systems measure exhaled CO_2 directly from the airway, whereas sidestream systems measure exhaled CO_2 via a nasal-oral cannula[1]. Sidestream $etCO_2$ measurements are an average of 3 mmHg higher than mainstream measurements, according to Pekdemir et al[3]. In the past, mainstream systems required patients to be intubated; however, modern mainstream $etCO_2$ sensors are noninvasive and do not require intubation[4]. Thus, both mainstream and sidestream systems can be used for both intubated and non-intubated patients. However, sidestream measurements are less accurate due to the increase in dead space resulting from suction catheters or blocking of the catheter by fluids and secretions. As a result, in the prehospital setting, further use of capnography in the prehospital setting should use only mainstream measurements for clinical determinations. Capnography monitors can be portable or attached to a comprehensive vitals monitor and can provide capnograms seconds after the monitor is secured.

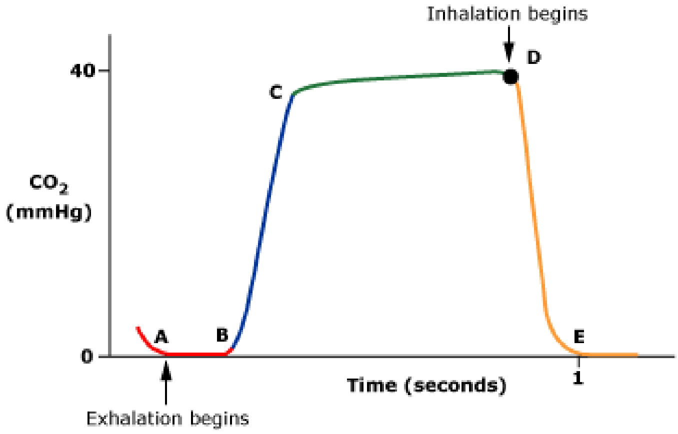

Figure 1: Normal CO2 waveform - reproduced from Krauss & Falk[1]

In the hospital setting, capnography is a routine element of monitoring patients receiving general anesthesia. During surgery on an intubated patient, capnography allows healthcare providers to rapidly determine when there is a rapid drop in lung perfusion, when the advanced airway is not placed correctly, or when there is an equipment or anesthesia malfunction[5]. In the prehospital setting, capnography is the most accurate means of confirming endotracheal tube (ETT) placement. For this purpose, capnography serves as a validation method, because it can quickly provide the indication that an ETT is placed correctly to allow for ventilation to occur.

Here I present a literature review on the uses of capnography and draw attention to its promising applications to improve patient care in the prehospital setting. This paper evaluates the how capnography can improve patient health outcomes through its prognostic value and its potential to improve EMS operations. First, I evaluate the prognostic value of capnography, or the ability for capnography to improve disease diagnosis in the prehospital and hospital setting. I collected scholarly articles supporting capnography's prognostic value for a number of disorders and systematically reviewed their findings to ascertain capnography's practical diagnostic value. Next, I evaluate the ability for capnography to improve EMS operations, with a focus on triage. I synthesized information from previous literature that supported capnography's practical ability to improve triage and EMS operations, and patient health outcomes as a result. Finally, I summarized findings and analysis into a field manual and triage flowchart that would allow BLS providers to utilize the benefits of capnography without ALS training.

2. Discussion

2.1. Prognostic Value of Capnography

In the prehospital setting, field diagnoses made by EMS providers, especially AEMTs and paramedics, allow providers to treat patients before they enter the hospital. Additionally, field impressions made by EMS providers can aid hospitals in determining the level of care a patient may need, as shown by Simmons[5], who asserted that paramedic field impressions improve hospital trauma triage ($p<0.001$). Current literature supports capnography's prognostic value, and thus value for improving patient health outcomes through diagnosis, for a variety of cardiopulmonary, metabolic, and trauma-related disorders.

Capnography has prognostic value for airway obstruction and certain pulmonary diseases. According to Taniguchi[6], for patients with a pulmonary embolism (PE), the gradient between maximum partial pressure of CO2 (PaCO2) in the blood and $etCO_2$ increases from 4.6 mmHg to 22 mmHg. Taniguchi purports that this allows for the prediction of PE; however, PaCO2 is not routinely measured in the prehospital setting, so this has little practical prognostic value in the prehospital setting. Extending the connection between capnography and PE posited by Taniguchi, Hemnes[7] asserts that pulmonary embolism can be ruled out using an $etCO_2$ cutoff of 36 mmHg with a negative predictive value of 0.966 (p. 738). In addition, $etCO_2$ is not the only aspect of capnography that can have predictive value in the prehospital field – the shape of the capnogram can have prognostic value for lung disease. According to Krauss & Falk[1], the plateau phase of the capnogram of a patient suffering from bronchospasm will have a sharper slope. Duckworth[8] maintains that the expiratory plateau of the capnogram slopes downwards for patients with emphysema or a pneumothorax, because the alveoli leak, causing an uneven expulsion of CO2. Krauss & Falk[1] contend that hyperventilation and hypopneic hypoventilation both produce short waveforms, with a high and low respiratory rate, respectively. For bradypneic hypoventilation, the capnogram rises and grows larger horizontally as time passes. According to Krauss & Falk[1], in patients with a partial airway obstruction or partial laryngospasm, the capnogram will appear normal, though the patient will have noticeable dyspnea. As a result, the capnogram can rule out other causes of dyspnea, such as bronchospasm, COPD, or asthma. Duckworth[8] asserts that for an airway obstruction or laryngospasm that causes hypoxia, the waveform has a "shark-fin" appearance, with a gently sloping expiratory phase. Since the severity of the airway obstruction or laryngospasm causes differing capnograms, capnography can enable EMS personnel to determine the severity of the obstruction and alert the receiving hospital. However, Duckworth[8] also reports that a hypoxic asthma patient's capnogram appears the same as the waveform produced by an airway obstruction. Thus, a differential diagnosis between asthma and airway obstruction is not possible with only capnography – a complete physical exam is needed. Though the shape of capnograms can have prognostic value for lung conditions, its limiting factor is that it is a qualitative rather than quantitative measurement, in contrast to $etCO_2$ alone. Thus, EMS personnel would need to receive additional training to read capnograms, whereas for $etCO_2$'s prognostic value, little training is needed.

Additionally, capnography can be used to differentiate between cardiac causes of dyspnea and obstructive causes of dyspnea in the prehospital setting. Hunter[9] and Mieloszyk[10] purport that capnography can distinguish between congestive heart failure (CHF) and chronic obstructive pulmonary disorder (COPD), which are cardiac and obstructive causes of dyspnea, respectively. Hunter asserts that $etCO_2$ measurements in the prehospital setting can differentiate between dyspnea secondary to CHF and COPD because $etCO_2$ is significantly lower in CHF patients compared to the $etCO_2$ of COPD patients. Hunter determines that a value of 40 mmHg or lower predicts CHF ($p<0.001$). Similarly, Mieloszyk et al[10] agree that capnography can be used to differentiate between CHF and COPD in the prehospital setting, by using a machine learning algorithm that learns from slopes, angles, and curves on the patient's capnogram. However, Mieloszyk et al derive prognostic value from the shape of the capnogram, whereas Hunter uses only the $etCO_2$ value. Both authors claim capnography has prognostic value for dyspnea, but Mieloszyk does so using the waveform (qualitative) and Hunter does so through just the $etCO_2$ value (quantitative), using an $etCO_2$ cutoff of 40 mmHg.

Furthermore, capnography has predictive value in determining the severity of trauma. Williams et al[11] allege that $etCO_2$ significantly correlated with "severe injury," which they defined as "admission to an intensive care unit, need for an invasive procedure, blood product transfusion, acute blood loss anemia, and acute clinically significant finding on computed tomographic scan" (p.2146), because they found an $etCO_2$ value below 30.5 mmHg correlated with a greater incidence of "severe injury" ($p<0.01$) (p. 2147). Childress et al[12] support Williams' data, claiming that, in a sample of acute trauma patients, deceased patients had significantly lower $etCO_2$ values ($p<0.001$) than patients who survived hospital discharge. However, Williams argues that $etCO_2$, though it correlates to "severe injury," does not provide practical prognostic value because the difference in $etCO_2$ between patients with and without "severe injury" was only 2.8 mmHg, and the cutoff $etCO_2$ value of 30 mmHg had a specificity of 0.5, which the authors determined had low clinical value (p. 2148). On the other hand, Childress claims that $etCO_2$ can gauge the severity of trauma with a cutoff $etCO_2$ value of 30 mmHg, which they determined significantly predicts mortality ($p=0.001$) in trauma patients with a sensitivity of 0.89 and a specificity of 0.68 (p. 172). Childress et al noted a stronger association between $etCO_2$ and trauma severity than was noted by Williams, as evidenced by the higher sensitivity and specificity associated with a similar cutoff $etCO_2$ value.

In addition, $etCO_2$ predicts metabolic acidosis, due to $etCO_2$'s correlation with serum lactate or serum bicarbonate levels. Hunter et al[13] found that there was a significant ($p<0.001$) negative correlation between lactate and $etCO_2$ in patients with both sepsis and severe sepsis. Given that lactate is a predictor of metabolic acidosis, Hunter claimed that $etCO_2$, thus, correlates with acidosis[13]. In contrast, Nagler[14] determined that there is a significant correlation between $etCO_2$ and serum bicarbonate ($r=0.80$) in children with gastroenteritis. Serum bicarbonate levels also correlate with metabolic acidosis, so Nagler reaches the same conclusion as Hunter. Additionally, Soleimanpour[15] found a significant positive correlation between $etCO_2$ and bicarbonate levels ($p<0.0001$), which he argued provided a mechanism for why $etCO_2$ capnograms are lower in patients with diabetic ketoacidosis. Since bicarbonate levels are lower in DKA patients, due to acidosis, it causes a corresponding decrease in $etCO_2$. As a result, Soleimanpour[15] claims that capnography has predictive value in ruling out diabetic ketoacidosis based on a cutoff $etCO_2$ value of 24.5 mmHg, with a sensitivity and specificity of 0.90. Hunter et al[16] argue that a cutoff $etCO_2$ value of 25 mmHg predicts both sepsis ($p<0.001$) and severe sepsis ($p<0.001$) when utilized as a measure of hypoperfusion as part of a sepsis screening tool that integrates other vital signs as well. Hunter[16] agreed that there is a significant correlation between $etCO_2$ and bicarbonate levels ($p<0.001$) and between $etCO_2$ and lactate ($p<0.001$), supporting the conclusions of Hunter[13], Nagler[14], and Soleimanpour[15], and posit this correlation as an explanation for the predictive validity of $etCO_2$ for sepsis and severe sepsis.

Due to its correlation with lactate and serum bicarbonate, capnography can also have predictive value for the severity of shock, however further research is needed to determine cutoff $etCO_2$ values to make capnography useful for shock prognosis in the prehospital setting. According to Weil[17], $etCO_2$ measured sublingually (known as $P_{SL}CO_2$) can predict circulatory shock. Weil reports that a $P_{SL}CO_2$ cutoff of 70 mmHg predicts circulatory shock with a positive predictive value of 1.00 and a negative predictive value of 0.93 (p. 1227). However, further research is needed to replicate the study with mainstream or sidestream $etCO_2$ rather than $P_{SL}CO_2$, as the $etCO_2$ values differ if measured through mainstream/sidestream devices versus sublingual devices. In agreement with Weil, Stone[18] asserts that $etCO_2$ has a strong association with hemorrhagic shock in trauma patients and can predict the severity of the patient's condition in the first six hours of admission. Stone reports that the mean $etCO_2$ for patients with a shock index (SI) > 0.9, indicating hemorrhagic shock in the study population, was significantly lower than patients with an SI < 0.9 (29.9 vs. 34.9, $p=0.037$) (p. 54). However, Stone does not provide a cutoff $etCO_2$ value, sensitivity, nor specificity, so additional research is needed to determine an $etCO_2$ cutoff value for predicting hemorrhagic shock. Duckworth[8] supports the relationship between $etCO_2$ and shock by purporting that shock is associated with a change in the capnogram shape. Duckworth claims that the capnography waveform trends down in shock; however, since this is a qualitative measurement, EMS personnel would need to receive additional training to read capnograms, which could impede its prognostic value to improve health outcomes in the prehospital setting.

Though capnography has many potential uses to improve patient health outcomes in the prehospital setting, a number of factors may limit its usefulness. Garnett[19] asserts that consumption of carbonated beverages or antacids can cause an artificial increase in a patient's exhaled pCO2 that is not tied to the pulmonary system of the patient. This can provide false-positive evidence of endotracheal intubation, when an esophageal intubation has occurred instead. However, Garnett also notes that, after six breaths, the capnogram usually determines whether the intubation is endotracheal or esophageal accurately. Additionally, the artificial rise in the capnogram waveform caused by carbonated beverages or antacids may falsely indicate that a patient's ventilation is inadequate or cause a patient's $etCO_2$ to appear out of acceptable ranges, which may reduce capnography's prognostic value. Further, Okamoto[20] note that the use of sodium bicarbonate increases a patient's $etCO_2$ for five to ten minutes after administration. Ornato[21] and Tang[22] support the connection between drug administration and drug-induced changes in $etCO_2$. Ornato shows that $etCO_2$ decreases after the administration of vasopressor drugs; similarly, Tang indicates that $etCO_2$ decreased by half after epinephrine administration in rodents. As a result, the administration of sodium bicarbonate, vasopressors, and epinephrine, in the prehospital setting by ALS providers may render capnography unable to provide prognostic value for a short period of time following drug administration.

2.2. EMS Operations Improvement from Capnography

2.2.1. triage value of capnography

Capnography can be used as a triage tool due to its ability to rapidly measure a patient's perfusion status. Krauss et al[23] discuss how capnography can be used as a rapid assessment and triage tool for chemical terrorism. Krauss asserts that capnography provides a rapid assessment of airway, breathing, and circulation (ABCs), the three elements of perfusion, supported by Falk[24], Hunter[9], and Mieloszyk[10], who all maintained capnography's predictive value for cardiopulmonary abnormalities (cardiac arrest and CHF/COPD respectively). Though Krauss specifically addresses triage for chemical terrorism, all triage relies on quick measurement of a patient's perfusion status, and using capnography to measure ABCs accelerates this measurement to 15 to 30 seconds. Based on Krauss's conclusions, a modification of the START triage system to employ capnography as a measure of perfusion is shown in Figure 2. The START triage system rapidly assesses the ABCs to categorize patients into the following levels of severity, in ascending order: minor, delayed, immediate, and expectant. The modified START flowchart replaces three time-consuming elements of the START triage system (checking respiratory rate, assessing radial pulse, and assessing capillary refill) with a capnogram, which takes seconds to measure. Using the capnography triage flowchart would speed up the triage process by 15 to 30 seconds, in accordance with Krauss's conclusions[23]. Increasing the speed of triage through capnography would allow more patients to be evaluated and treated by EMS workers during a mass-casualty incident.

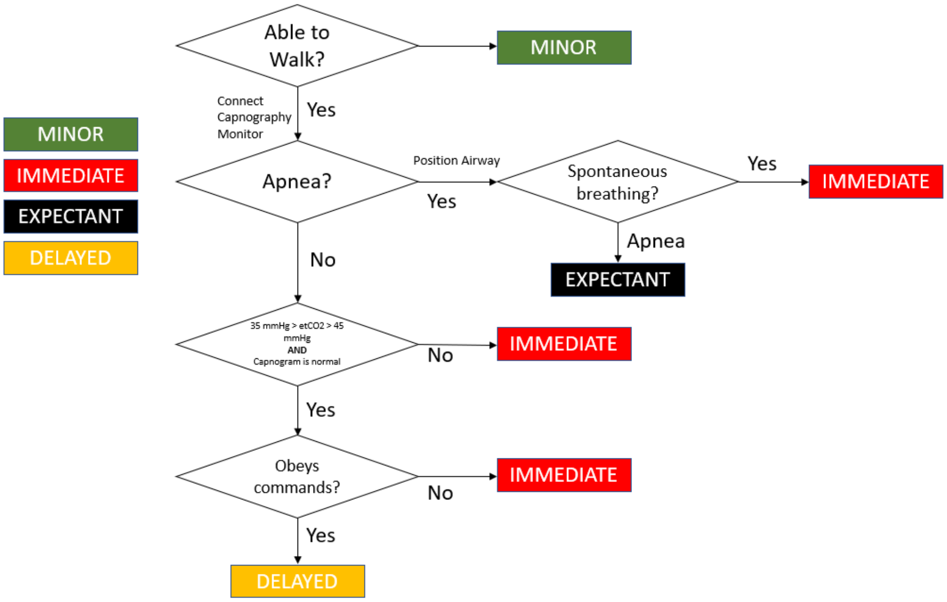

Figure 2: Potential Triage Flowchart Utilizing Capnography

Further, predicting mortality before time-intensive vital measurements and interventions are performed can cause a more effective allocation of EMS's time in situations where rapid triage is needed, like during a mass-casualty incident. Previous literature supports that capnography can predict mortality. Kheng et al[25] determined that, in patients suffering from hypoperfusion (shock), early $etCO_2$ measurements were significantly lower in patients who did not survive to hospital admission ($p<0.05$). If a patient had an $etCO_2$ less than 12 mmHg upon arrival to the ED, the patient would not survive to hospital admission. Though Kheng's article pertained solely to shock patients, Hunter et al[13], in contrast, focused on in-hospital mortality for patients with suspected sepsis. Hunter also agrees that capnography predicts mortality, with an AUC of 0.73 for a ROC curve analyzing capnography's predictive value for mortality. In a 2013 study, Hunter et al[26], expanding on their 2012 work, evaluated $etCO_2$'s ability to predict in-hospital mortality compared to other vital signs. They determined that $etCO_2$ was the strongest predictor of mortality ($p<0.001$), stronger than respiratory rate, BP, pulse, and SpO2. This conclusion was consistent with Kheng's[25] and Hunter's[13] articles. Unlike Kheng and Hunter, who obtain statistical evidence for their conclusion, Krauss's article is a "proof-of-concept" – he does not perform a study; rather, he posits a theoretical use for capnography with supporting evidence.

Additionally, capnography has value in evaluating CPR in patients suffering from cardiac arrest. In a study measuring $etCO_2$ during 13 episodes of cardiac arrest, Falk[24] claims that, for patients suffering from cardiac arrest, capnography can monitor the efficacy of chest compression and determine when circulation has been restored. The researchers concluded that the increase in a patient's $etCO_2$ reading after the initiation of chest compressions indicates that the CPR being provided to a patient is adequate. Sheak[27] agreed that there is a correlation between chest compression and $etCO_2$, asserting that for every 10 mm in depth of chest compression, $etCO_2$ was elevated by 1.4 mmHg ($p<0.001$) (p. 151). Krauss & Falk[1] propose that $etCO_2$ monitors efficacy of CPR during cardiac arrest because ventilation and metabolism are constant during cardiac arrest, so $etCO_2$ only reflects pulmonary blood flow during CPR on cardiac arrest patients. According to Aminiahidashti[28], AHA guidelines emphasize that continuing chest compressions without interruption until a perfusing rhythm is reestablished. Capnogram monitoring eliminates the need to cease chest compressions to check for pulse, thereby increasing the cardiac arrest patient's chance of survival.

Capnography also has prognostic value in predicting mortality and return of spontaneous circulation (ROSC) in cardiac arrest patients. Falk[24] concluded that the spike in $etCO_2$ to 3.7% and the following elevation of $etCO_2$ (2.6% from 1.4% before cardiac arrest) is a unique pattern that proves return of spontaneous circulation (ROSC) has occurred. Sheak[27] also identifies a correlation between $etCO_2$ and ROSC, stating that the average $etCO_2$ for patients with ROSC was higher compared to patients without restoration of pulse (34.5 vs. 23.1 mmHg, $p < 0.001$) (p. 151). Cantineau[29] and Callaham[30] add that $etCO_2$ can predict ROSC with high sensitivity. Cantineau determined that $etCO_2$ in asystole patients during the first 20 minutes after intubation predicts ROSC with a sensitivity and specificity of 1.00 and 0.66, respectively, using a cutoff $etCO_2$ value of 10 mmHg (p. 793). Callaham, however, asserts that an $etCO_2$ cutoff of 15 mmHg predicts ROSC with a sensitivity and specificity of 0.71 and 0.98 (p. 358), a lower sensitivity but higher specificity than Cantineau's 10 mmHg cutoff. In the prehospital setting, EMS providers could utilize a cutoff of 10 mmHg or 15 mmHg depending on the desired sensitivity and specificity. For the purposes of mass-casualty triage, a higher specificity cutoff (15 mmHg) is likely more desirable, in order to ensure the EMS providers' time is being used most effectively. Levine[31] extends the work of Falk, Cantineau, and Callaham to ascertain capnography's predictive value for survival to hospital admission, instead of its predictive value for ROSC. Levine claims that a cutoff $etCO_2$ of 10 mmHg for 20 minutes predicts pre-hospital admission mortality with a sensitivity and specificity of 1 (p. 303). Ahrens[32] supports this claim, asserting that $etCO_2$ can accurately predict the mortality of patients in cardiac arrest with a cutoff of 10 mmHg, as patients with $etCO_2$ greater than 10 mmHg had a significantly higher survival rate ($p<0.001$) than those with $etCO_2$ less than 10 mmHg. The difference between Callaham's 15 mmHg cutoff for ROSC and Levine and Ahrens' 10 mmHg cutoff for mortality can be attributed to the fact that ROSC does not equate to pre-hospital admission survival – a patient can undergo ROSC yet fall back into cardiac arrest and die before arrival at the hospital. Thus, given that pre-admission mortality rate is a superior measure of final patient health outcomes than ROSC, and $etCO_2$ provides a more robust predictive value when predicting mortality rather than ROSC, an $etCO_2$ cutoff of 10 mmHg for cardiac arrest patients should be used by EMS personnel to maximize patient health outcomes. Levine and Ahren's conclusions imply that $etCO_2$ can be used as a determining factor in the decision to cease resuscitation, as cardiopulmonary resuscitation may reasonably be terminated in cardiac arrest patients with $etCO_2$ at or below their cutoff of 10 mmHg.

2.2.2. other EMS operations improvements from capnography

One limitation of capnography is that reading capnograms is typically an advanced life support (ALS) skill that only AEMTs and paramedics can perform. However, Krauss[23] asserts that capnography is straightforward to use by EMS personnel who are unaccustomed to it. Krauss explains that capnographs are available as plastic oral-nasal cannulas, which EMT-Bs are able to apply to a patient. This allows the prognostic and triage capabilities of capnography presented earlier to be employed by EMT-Bs. Additionally, the algorithm presented by Mieloszyk[10], used to distinguish between CHF and COPD patients, is an automatic method to read capnograms which allows EMT-Bs, who are untrained in reading capnograms, to utilize capnography and removes the element of human error from capnography. Soleimanpour[15], Williams[11], Childress[12], Hunter[9], Hunter[13], Nagler[14], Kheng[25], Hunter[26], Hemnes[7], Weil[17], Cantineau[29], Callaham[30], Levine[31], and Ahrens[32] all posit cutoff $etCO_2$ values to predict or rule out certain conditions (shown in Table 1). The aforementioned articles indirectly bring the ALS skill of reading capnograms into the realm of BLS care – Mielosyzk achieves this through an algorithm that automatically reads capnograms, and the other articles achieve this through using a cut-off $etCO_2$ value displayed on a monitor that need only be read and recorded by an EMT-B in order to predict or rule out certain conditions in the prehospital setting. AEMTs are not always available when a patient requires emergency medical services, so providing EMT-Bs with capnography-related diagnostic and triage skills would allow the benefits of capnography to be used on more patients requiring EMS care.

Furthermore, capnography allows for the continuous monitoring of the ventilation status of patients during transport, due to its ability to monitor ETT tube placement. An ETT tube may become dislodged or misaligned during a patient's transport (known as unrecognized misplaced intubation – UMI), and an EMS worker must dedicate their attention to ensure this does not occur in patient, which can detract from their ability to provide care to the other injuries of the intubated patient or other patients. Krauss and Falk[1] assert that UMI rates range from 7 to 25 percent, and use of $etCO_2$ to confirm ETT placement may help prevent UMI. Silvestri[33] supports Krauss's conclusion, reporting that no UMIs were found in patients for whom paramedics used continuous $ETCO_2$ monitoring, whereas failure to use continuous $ETCO_2$ monitoring was associated with a 23% UMI rate. Duckworth[8] supports the connection between capnography and monitoring ETT placement, demonstrating that the shape of the capnogram is altered when an UMI occurs. Duckworth contends that a full displacement of airway causes a sudden drop in the capnogram while a partial airway placement issue causes a deformation in the shape. Utilizing capnography to monitor ETT tube placement enables EMS personnel to divert much of their attention to other injuries, albeit with the occasional glance to the capnography monitor to ensure ETT placement, which allows EMS workers to provide additional patient care.

As mentioned in the Triage section, Kheng et al[25], Hunter[13], and Hunter[26] show that capnography can be used to predict prehospital mortality. Determining future mortality (without potential for lifesaving treatment) before time-intensive vital measurements and interventions are performed can cause a more effective allocation of EMS's time. EMS personnel can shift their focus from life-saving maneuvers to palliative care options, which improves the quality of a patient's life. Additionally, this can improve EMS response time and more resources can be allocated to higher priority patients, which has a positive impact on the health outcomes of the EMS agency's community as a whole.

The prognostic and EMS improvement uses of capnography are summarized in the following table:

Table 1. Field Manual of the Uses of End-Tidal Carbon Dioxide

Author	Purpose	$etCO_2$ cutoff	Sensitivity, Specificity	PPV, NPV	AUC for ROC curve
Cantineau[29]	Predict ROSC in asystole patients	>10 mmHg	1.00, 0.66	NR	NR
Callaham[30]	Predict ROSC in asystole patients	>15 mmHg	0.71, 0.98	0.91, 0.91	NR
Levine[31]	Predict pre-hospital admission mortality in cardiac arrest patients	<10 mmHg	1.00, 1.00	1.00, 1.00	NR
Ahrens[32]	Predict pre-hospital admission mortality in cardiac arrest patients	<10 mmHg	NR	NR	NR
Kheng[25]	Predict prehospital mortality	<12 mmHg	1.00, 1.00	1.00, 1.00	1.00
Soleimanpour[15]	Rules out DKA	>24.5 mmHg	0.90, 0.90	NR	NR
Childress[12]	Predict mortality in acute trauma	<30 mmHg	0.89, 0.68	0.13, 0.99	0.84
Hunter[13]	Predict lactate in suspected sepsis	<30 or >40 mmHg	NR	NR	0.75
	Predict mortality in suspected sepsis	<30 or >40 mmHg	NR	NR	0.73
Williams[11]	Fails to predict severe injury	<30.5 mmHg	0.77, 0.5	NR	0.70
Nagler[14]	Predict serum bicarbonate	<31 mmHg	0.76, 0.96	NR	0.96
Hunter[26]	Predict in-hospital mortality	<31 mmHg or >41 mmHg	0.93, 0.44	NR, 0.99	0.76

Hunter[16]	Predict sepsis	NR	0.69, 0.67	0.47, 0.93	0.99
	Predict severe sepsis	NR	0.76, 0.46	0.11,0.95	0.80
	Predict serum bicarbonate	<34 mmHg	1.00, 0.60	NR	0.96
Hemnes[7]	Rule out pulmonary embolism	>36 mmHg	0.87, 0.53	NR, 0.966	NR
Hunter[9]	Differentiation between cardiac/obstructive dyspnea	<40 mmHg (CHF)	0.93, 0.43	0.38, 0.94	0.70
Weil[17]	Predict circulatory shock	>70 mmHg	NR	1.00, 0.93	NR

*NR = Not Reported

3. Conclusion

Capnography has a variety of uses – including prognostic value, triage potential, and potential to improve EMS operations – that can improve patient health outcomes in the prehospital setting. The etCO$_2$ values for which capnography predicts or rules out certain conditions are enumerated in Table 1, a manual that EMS personnel can use as a resource to easily utilize capnography's prognostic value.

Though there are many limitations to capnography's value for prognosis, triage, and EMS operations improvement, capnography is underutilized in the prehospital setting, and the adoption of capnography monitors and capnography training for EMT-Bs would improve health outcomes in an EMS agency's area of care.

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