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REVIEW

Applications of capnography in airway management outside the operating room

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Abstract

The capnograph is vital for patient monitoring in the operating room. Its clinical applications for airway management outside the operating room are being increasingly recognized due to its role in the Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Guidelines. Capnography can be used for the detection of respiratory depression during procedural sedation, verification after emergency endotracheal tube intubation, assessment of the airway and circulation during cardiopulmonary resuscitation, and continuous monitoring during patient transportation and in intensive care settings. This can be especially beneficial for pediatric patients, those who are critically ill, and patients with a difficult airway.

Keywords

Capnography; Capnometer; Airway management; Patient transport; Difficult airway

1. Introduction

Carbon dioxide (CO_2) in exhaled breath is an important physiologic indicator of ventilation, pulmonary circulation, and aerobic metabolism [1]. Over the years, numerous publications examining CO_2 monitoring for clinical purposes have been produced. A capnograph is a noninvasive monitor that measures the partial pressure of CO_2 and reports its numeric value. It produces a capnogram that displays the continuous graphic waveform of CO_2 partial pressure over time. A normal capnogram (Fig. 1) depicts a square-wave pattern consisting of four phases, revealing the CO_2 concentration over the period of respiration [2]. It starts at the inspiratory phase and continues until the expiratory phase, with the waveform having a rounded rectangular shape. The peak measurement at the end of phase III is the $EtCO_2$ reading. The target $EtCO_2$ value is 35–45 mmHg, with a typical rate of ventilation for a spontaneously-breathing adult of 12–20 breaths per minute [3]. Trends in $EtCO_2$ value, rate, and waveform pattern should be stable for healthy adults.

The $EtCO_2$ and the recognizable waveform can provide crucial information on underlying physiologic conditions. However, the value of capnography is underacknowledged, and it is rarely used outside the operating room. From the perspective of anesthesiology, the purpose of this review article is to reaffirm the benefits of capnography in regards to airway management and the enhancement of patient care.

2. Clinical applications of capnography in airway management

Capnography has been a routine method of monitoring anesthesia in the operating room for more than 30 years [1, 4]. The auscultation of breath sounds and normal capnography waveforms from the airway help to quickly confirm endotracheal tube (ETT) placement in patients requiring intubation for general anesthesia. Capnography is becoming the international standard for safe anesthesia practice [5–7]. A portable capnograph or capnometer can also be beneficial for airway management outside the operating room, especially in an emergency context [8, 9]. Common applications for capnography in airway management are as follows.

2.1 Detection of respiratory depression during procedural sedation

Many sedatives or analgesics affect respiratory depression by reducing the respiratory rate or tidal volume. A multicenter observational study reported that adverse events, mostly hypoxia and apnea, occurred in 11% of cases in which patients underwent procedural sedation [10]. Capnography is suggested for patients expected to receive moderate or deep procedural sedation [11, 12]. Capnographic assessment provides the ventilation waveform, respiratory rate, and $EtCO_2$, which are used to predict hyperventilation from inadequate analgesia as well as hypoventilation from oversedation (Table 1) [13]. Capnography helps health care providers titrate medication for patients, especially older adults, provides early warning signs of adverse respiratory events during procedures, and enhances patient care.

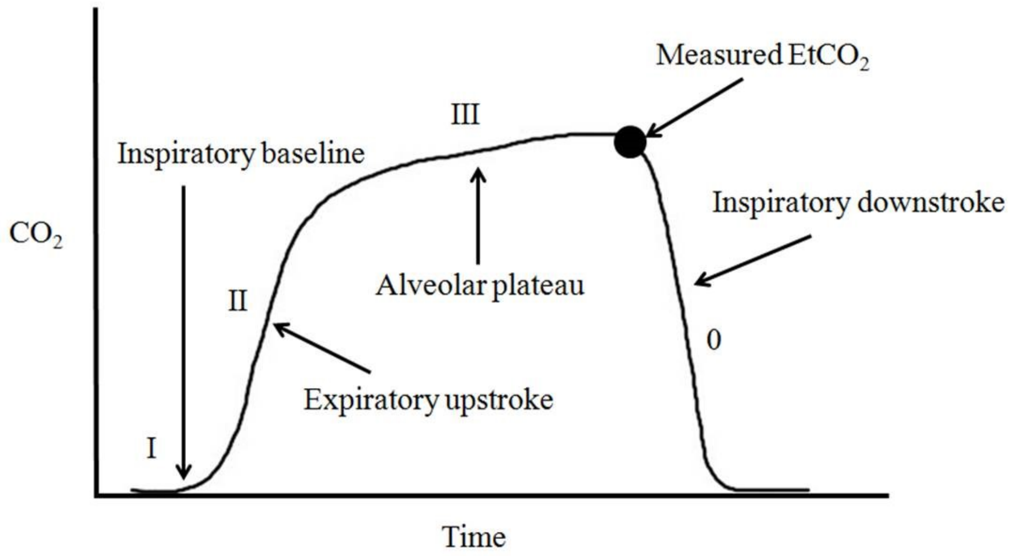


FIGURE 1. Normal capnography waveform. Phase I is the inspiratory baseline, with a low CO_2 level during inspiration. Phase II is the expiratory upstroke. Phase III is the alveolar plateau, reflecting the alveolar expiratory flow, which reaches its peak at the end of tidal expiration ($EtCO_2$). Phase 0 is the inspiratory downstroke.

2.2 Verification after emergent ETT intubation

A misplaced ETT in a location other than the trachea is a fatal condition. $EtCO_2$ monitoring is the gold standard method for confirmation of ETT placement in the trachea [14–17]. A multicenter study found the colorimetric $EtCO_2$ device to be highly accurate for confirming ETT position in non-cardiopulmonary arrest patients [18]. Furthermore, intubation guidelines in the intensive care unit instruct the use of capnography to verify tube placement [19]. After intubation, a flat capnographic trace indicates additional airway problems, such as that the breathing circuit is disconnected, the airway is kinked or blocked with secretions, or the patient has bitten and occluded the tube. Guidelines issued for managing airways in patients with emerging infectious diseases, such as coronavirus disease 2019 (COVID-19), suggest capnography for every tracheal intubation [20].

2.3 Assessing the airway and circulation during cardiopulmonary resuscitation

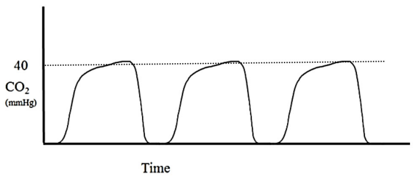
Initial airway management support during cardiopulmonary resuscitation (CPR) usually involves the operation of a bag valve mask (BVM). A systematic review suggested that capnography can facilitate the advanced clinical practice of mask ventilation in CPR [21]. During CPR, the presence of CO_2 waveforms from the ETT verifies its location [22]. $EtCO_2$ reflects pulmonary blood flow and becomes a real-time indicator in evaluating the effectiveness of cardiac compressions [23]. High quality chest compressions are achieved when $EtCO_2$ is at 10–20 mmHg. Moreover, an abrupt increase in $EtCO_2$ (35–45 mmHg) may indicate the return of spontaneous circulation (Table 2) [23, 24].

2.4 Continuous monitoring during transport of patients who are critically ill

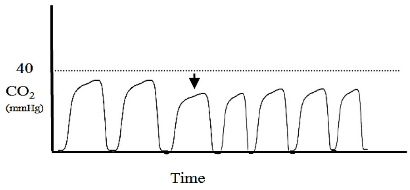
Until recently, the capnograph was not a standard monitor for the intrahospital transport (IHT) of patients who are critically ill [25]. However, it provides at least two advantages during IHT. First, the unplanned extubation of an ETT may occur during IHT, and capnography helps in the early detection of ETT dislodgement. Continuous CO_2 monitoring is the most reliable method of detecting the dislodgement of an ETT or tracheostomy tube during anesthesia [1]. Changes in oximetry readings are often delayed due to oxygen supplementation; therefore, improving the speed of detecting misplaced intubation would be helpful for prehospital patient transport [26, 27]. A prospective clinical study revealed that a combination of pulse oximetry and capnometry enables the detection of potentially life-threatening problems in patients undergoing ventilation during IHT [28]. For pediatric patients who are critically ill, capnography is recommended for confirming the ETT position during transport [29].

Second, capnography can be a noninvasive estimation of cardiac output [30, 31]. A sudden decrease in $EtCO_2$ that retains a square waveform may suggest a sudden decrease in lung perfusion caused by either an obstruction to pulmonary blood flow, such as a thrombus, air, or fat, or a reduced cardiac output. The conditions of patients who are critically ill and require high-dose vasopressor therapy, patients experiencing hypothermia with low local temperature in their limbs, and the agitated state of a patient may affect pulse readings [32, 33]. Capnography provides additional information in such unstable hemodynamic conditions during IHT.

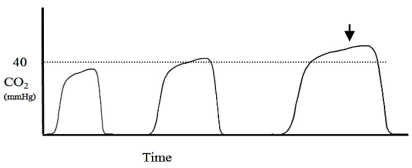
TABLE 1. Capnographic assessment during procedural sedation.



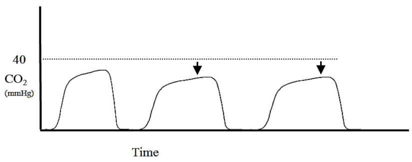
1.1 Normal capnography
Normal $EtCO_2$
Normal waveform amplitude
Normal respiratory rate
Dotted line: baseline $EtCO_2$ at 40 mmHg



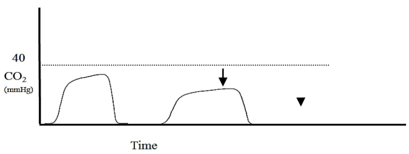
1.2 Hyperventilation
Decreased $EtCO_2$
Decreased waveform amplitude
Decreased respiratory rate
Arrow: $EtCO_2$ decline from baseline



1.3 Bradypneic hypoventilation
Increased $EtCO_2$
Increased waveform amplitude
Decreased respiratory rate
Decreased tidal volume (mild)
Arrow: $EtCO_2$ increase from baseline

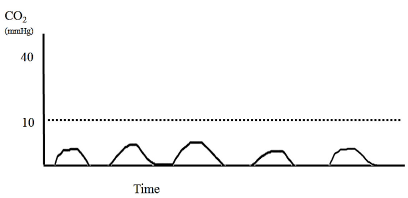


1.4 Hypopneic hypoventilation
Decreased $EtCO_2$
Decreased waveform amplitude
Decreased respiratory rate (mild)
Decreased tidal volume
Arrow: $EtCO_2$ decline from baseline

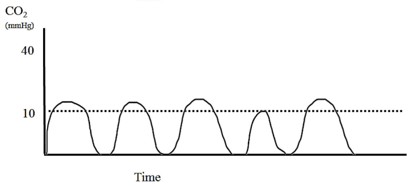


1.5 Hypoventilation and apnea
$EtCO_2$ of zero
Absent waveform
Respiratory rate of zero
Arrow: $EtCO_2$ decline from baseline
Arrowhead: absent waveform

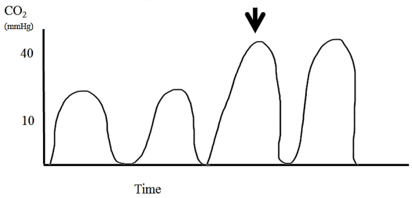
TABLE 2. Capnographic assessment during cardiopulmonary resuscitation (CPR).



2.1 Ineffective chest compression
$EtCO_2 < 10$ mmHg during CPR
Dotted line: baseline $EtCO_2$ at 10 mmHg

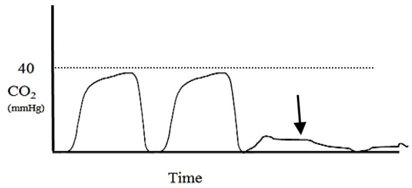
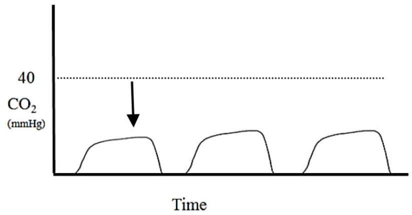
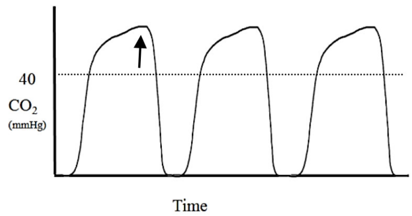
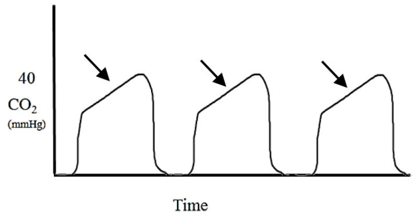
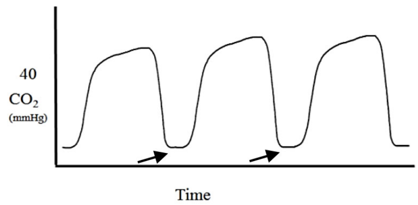
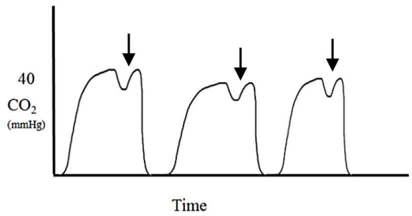


2.2 Effective chest compression
$EtCO_2 > 10$ mmHg during CPR



2.3 An abrupt increase in $EtCO_2$ may indicate a return of spontaneous circulation
Arrow: an abrupt increase in $EtCO_2$ greater than 10–15 mmHg

TABLE 3. Common abnormal capnography waveforms of patients undergoing intubation.

Capnography waveform	Clinical situations
	3.1 Sudden loss of waveform **DOPES** mnemonic: Displacement, obstruction, pneumothorax, equipment failure or kink, breath stacking Dotted line: baseline $EtCO_2$ at 40 mmHg Arrow: sudden loss of normal waveform
	3.2 Decreasing $EtCO_2$ Decreased CO_2 production, decreased pulmonary perfusion, increased alveolar ventilation, apparatus malfunction Arrow: $EtCO_2$ decline from baseline
	3.3 Increasing $EtCO_2$ Increased CO_2 production, increased pulmonary perfusion, decreased alveolar ventilation, equipment malfunction Arrow: $EtCO_2$ increase from baseline
	3.4 "Shark fin" or "ascot-hat" appearance Asthma, chronic obstructive pulmonary disease, bronchospasm Arrow: "shark fin" waveform in phase III
	3.5 Elevation of baseline and plateau Insufficient expiratory time, inadequate inspiratory flow, or faulty expiratory valve Arrow: inspiratory baseline elevation from zero
	3.6 Small dip in the alveolar plateau (known as "curare cleft") The patient attempts to breathe during partial paralysis Arrow: a small dip in phase III

2.5 Capnography in the intensive care unit

A prospective study by the Royal College of Anaesthetists and the Difficult Airway Society recommended continuous capnography monitoring in all patients with an artificial airway [30]. Failure of artificial airways has contributed to more than 70% of intensive care unit (ICU)-related deaths involving the airway.

2.6 Capnography and pediatric patients

As in adults, capnography offers benefits in the treatment of pediatric patients. Studies have reported high incidences of esophageal intubation in the pediatric emergency department and neonatal and pediatric ICU [34–36]. A review article revealed that capnography is a useful for the perioperative monitoring of a child's physiology and safety [37]. Continuous capnographic monitoring is also suggested in pediatric ICUs [38].

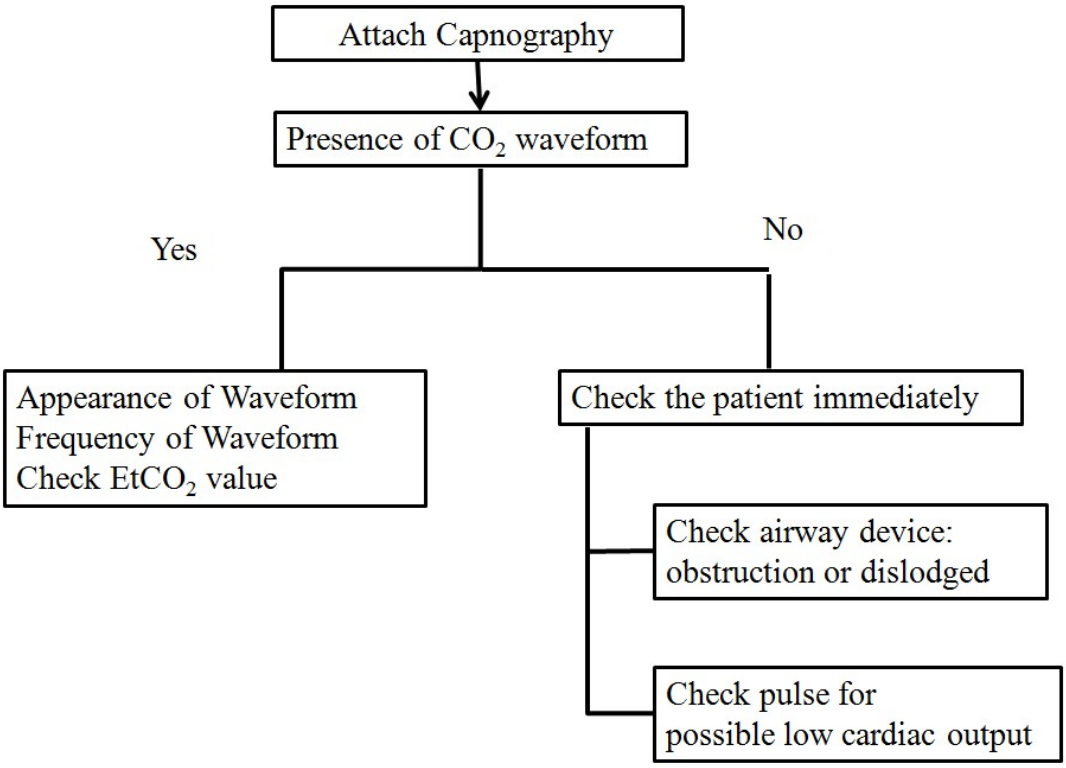


FIGURE 2. Algorithm for analyzing a capnography waveform.

3. Difficult airway and capnography

Difficult airway is a challenge for physicians; an observational study reported that 4% of patients who received advanced airway management in an emergency department experienced difficult intubation [39]. In the guidelines for difficult airway management, capnography can be used to confirm airway device ventilation, such as the placement of an ETT or a cricothyroidotomy, tracheostomy, or supraglottic airway device [40]. Studies have reported that capnography confirms ETT placement in 88%–100% of cases of difficult airway [41–43]. Capnography can also evaluate the effectiveness of mask ventilation [44, 45]. Thus, it may help first-line medical staff identify patients at high risk of difficult mask ventilation so that they can consult a specialist immediately. Capnography improves the safety of percutaneous tracheostomy by confirming the placement [46]. After the surgical airway is established, abnormal $EtCO_2$ values during transportation can indicate which circuit is disconnected or obstructed or if a tube is displaced [47, 48]. The early detection of airway dislodgment is vital, especially in patients with a difficult airway.

4. Discussion

Although much of the literature has recommended the clinical applications of capnography [22, 49–51], a scoping review revealed a link between capnography usage and a reduction in serious airway complications in the operating room, ICU, and emergency department and during resuscitation [52]. The 2020 American Heart Association Guidelines for CPR and Emergency Cardiovascular Care emphasize the use of capnography for intubated patients during CPR, and continuous waveform capnography, along with clinical assessment, remains the most reliable method of confirming and monitoring correct ETT placement [53]. Similar directives can be found in the Pediatric Advanced Life Support Guidelines. Exhaled CO_2 detectors should be assembled before intubation is attempted. At present, a miniature in-line waveform capnography device connected to a BVM could serve as an ideal, economical, portable $EtCO_2$ monitor. Such a device can benefit prehospital resuscitation, difficult airway management in emergency settings, and continuous monitoring during IHT. In addition to the incorporation of the CO_2 device into medical routines, education of first-line medical and nursing staff is crucial for ensuring the accurate interpretation of capnography values and waveforms. We suggest using an algorithm to analyze waveform capnography (Fig. 2). We summarize common abnormal capnography waveforms of patients undergoing intubation in Table 3 [2, 3, 54].

5. Conclusions

A capnograph or capnometer is a noninvasive airway monitor suitable for multiple clinical purposes outside the operating room. It provides a rapid and convenient method of confirming endotracheal tube placement immediately after intubation and tracheostomy. CO_2 monitoring during in-hospital transport for critically ill patients with artificial airways aids the early recognition of inadvertent tube dislodgement or hemodynamic change. It has been suggested for use as a routine monitor, especially for patients with difficult airways, as well as pediatric patients. It monitors airway and hemodynamic conditions in various steps of the health care process, such as airway management, resuscitation, transportation, procedural sedation, operation, and intensive care.

AUTHOR CONTRIBUTIONS

CHH reviewed the articles, wrote and drafted the manuscript. KHW drafted and revised the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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