AARC Clinical Practice Guideline

Capnography/Capnometry During Mechanical Ventilation: 2011

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We searched the MEDLINE, CINAHL, and Cochrane Library databases for articles published between January 1990 and November 2010. The update of this clinical practice guideline is based on 234 clinical studies and systematic reviews, 19 review articles that investigated capnography/ capnometry during mechanical ventilation, and the 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. The following recommendations are made following the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) scoring system: (1) Continuous-waveform capnography is recommended, in addition to clinical assessment to confirm and monitor correct placement of an endotracheal tube. (2) If waveform capnography is not available, a non-waveform exhaled CO_2 monitor, in addition to clinical assessment, is suggested as the initial method for confirming correct tube placement in a patient in cardiac arrest. (3) End-tidal CO_2 (P_{ETCO_2}) is suggested to guide ventilator management. (4) Continuous capnometry during transport of the mechanically ventilated patients is suggested. (5) Capnography is suggested to identify abnormalities of exhaled air flow. (6) Volumetric capnography is suggested to assess CO_2 elimination and the ratio of dead-space volume to tidal volume (V_D/V_T) to optimize mechanical ventilation. (7) Quantitative waveform capnography is suggested in intubated patients to monitor cardiopulmonary quality, optimize chest compressions, and detect return of spontaneous circulation during chest compressions or when rhythm check reveals an organized rhythm. *Key words: capnography; capnometry; colorimetric CO_2; end-tidal carbon dioxide; volumetric CO_2.* [Respir Care 2011;56(4):503–509. © 2011 Daedalus Enterprises]

CO₂ MV 1.0 DESCRIPTION

For the purposes of this clinical practice guideline, capnography refers to the evaluation of the CO_2 in the respiratory gases of mechanically ventilated patients. A capnographic device incorporates one of 2 types of sampling

techniques: mainstream or sidestream.[1] Mainstream technique inserts a sampling window into the ventilator circuit for measurement of CO_2, whereas a sidestream analyzer samples gas from the ventilator circuit, and the analysis occurs away from the ventilator circuit. Analyzers utilize infrared, mass or Raman spectra, or a photoacoustic spectra technology.[1,2] Flow measuring devices are utilized in volumetric capnographs. Colorimetric CO_2 detectors are a form of mainstream sampling, but are simplistic. The colorimetric CO_2 detector has a pH-sensitive chemical indicator that undergoes color change with each inspiration and expiration, thus reflecting the change in CO_2 concentration. These devices start at baseline color when minimal CO_2 is present and undergo gradual color change with increasing CO_2 concentration.[3]

CO₂ MV 2.0 PROCEDURE

Capnography is the continuous analysis and recording of the CO_2 concentration in respiratory gas. Although the

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terms capnography and capnometry are sometimes considered synonymous, capnometry means only the measurement of CO_2 in respiratory gas (ie, analysis alone), without a continuous written record or waveform. Capnographic waveforms may be time-based or volume-based.[4]

CO_2 MV 3.0 SETTING

Capnography can be performed by trained healthcare personnel in any setting in which mechanically ventilated patients are found.

CO_2 MV 4.0 INDICATIONS

There are 3 broad categories of indications for capnography/capnometry: verification of artificial airway placement; assessment of pulmonary circulation and respiratory status; and optimization of mechanical ventilation.

4.1 Verification of Artificial Airway Placement. Even when the endotracheal tube is seen to pass through the vocal cords and tube position is verified by chest expansion and auscultation during mechanical ventilation, providers should obtain additional confirmation of airway placement with waveform capnography or an exhaled CO_2 or esophageal detector device.[5]

4.1.1 Exhaled CO_2 detectors, including colorimetric and non-waveform, reliably detect intratracheal placement in patients whose cardiac output is not exceedingly low or who have not had prolonged circulatory failure. Their use in prolonged cardiac arrest merits further study.[5,6]

4.1.1.1 When waveform capnography is not available, these methods can be used in addition to clinical assessment as the initial method for confirming correct tube placement in a patient in cardiac arrest.

4.1.2 Capnography may be used as an adjunct to determine that tracheal rather than esophageal intubation has occurred.[4,7,8]

4.1.3 All intubations must be confirmed by some form of P_{ETCO_2} measurement.[5,9]

4.1.4 Effective ventilation through a supraglottic airway device such as the laryngeal mask airway (LMA) should result in a capnograph waveform during cardiopulmonary resuscitation (CPR), and after return of spontaneous circulation.[5]

4.1.5 When feasible, monitoring P_{ETCO_2} during chest compressions is encouraged.[5]

4.1.5.1 If the P_{ETCO_2} is < 10 mm Hg during CPR, the clinician should attempt to improve the quality of compressions.

4.1.5.2 An abrupt and sustained increase in P_{ETCO_2} is a sensitive indicator of return of spontaneous circulation.

4.1.6 P_{ETCO_2} monitoring is one of the objective standards required for monitoring patients in transport, to ensure integrity of the airway.[6,10,11]

4.1.6.1 Providers should observe a consistent capnographic waveform with ventilation to confirm and monitor endotracheal tube placement in the field, in the transport vehicle, on arrival at the hospital, and after any patient transfer, to reduce the risk of unrecognized tube misplacement or displacement.[5,12]

4.1.7 Capnography can be used to detect inadvertent airway intubation during gastric tube insertion.[13]

4.1.8 Life-threatening airway disasters and ventilator disconnection can be averted with continuous capnography.[14-16]

4.2 Assessment of Pulmonary Circulation and Respiratory Status. Capnography assists in:

4.2.1 Determining changes in pulmonary circulation and respiratory status sooner than pulse oximetry. In patients without lung disease, substantial hypercarbia may present before pulse oximetry notifies the clinician of a change in ventilation.[14,17-20]

4.2.2 Monitoring the adequacy of pulmonary, systemic, and coronary blood flow,[20,21] as well as estimation of the effective (non-shunted) pulmonary capillary blood flow by a partial rebreathing method.[22-24]

4.2.3 Evaluating the partial pressure of exhaled CO_2, especially P_{ETCO_2}.

4.2.4 Screening for pulmonary embolism.[25-28]

4.3 Optimization of Mechanical Ventilation. Capnography during mechanical ventilation allows:

4.3.1 Continuous monitoring of the integrity of the ventilator circuit, including the artificial airway[29] or bag mask ventilation, in addition to potentially detecting mechanical ventilation malfunctions.[30-32]

4.3.2 Decreasing the duration of ventilatory support.[33]

4.3.3 Adjustment of the trigger sensitivity.[34]

4.3.4 Evaluation of the efficiency of mechanical ventilation, by the difference between P_{aCO_2} and the P_{ETCO_2}.[35]

4.3.5 Monitoring of the severity of pulmonary disease[36,37] and evaluating the response to therapy, especially therapies intended to improve the ratio of dead space to tidal volume (V_D/V_T) and ventilation-perfusion matching ($\dot{V}/\dot{Q}$).[23,27,38-46]

4.3.6 Monitoring of $\dot{V}/\dot{Q}$ during independent lung ventilation.[47,48]

4.3.7 Monitoring of inspired CO_2 when it is being therapeutically administered.[49]

4.3.8 Graphic evaluation of the ventilator-patient interface. Evaluation of the capnogram may be useful in detecting rebreathing of CO_2, obstructive pulmonary disease, the presence of inspiratory effort during neuromuscular blockade (curare cleft), cardiogenic oscillations, esophageal intubation, and cardiac arrest.[50]

4.3.9 Measurement of the volume of CO_2 elimination to assess metabolic rate and/or alveolar ventilation.[43,51-53]

4.3.10 Monitoring of V_D/V_T to determine eligibility for extubation in children.[40,54]

4.3.11 There is a relationship between V_D/V_T and survival in patients with the acute respiratory distress syndrome.[55-57]

CO_2 MV 5.0 CONTRAINDICATIONS

There are no absolute contraindications to capnography in mechanically ventilated patients, provided that the data obtained are evaluated with consideration given to the patient's clinical condition.

O_2 MV 6.0 HAZARDS/COMPLICATIONS

Capnography with a clinically approved device is a safe, noninvasive test, associated with few hazards in most populations. Hazards/complications are different for the 2 types of capnographic device.

6.1 Mainstream

    6.1.1 Dead Space. Adapters inserted into the airway between the airway and the ventilator circuit should have a minimal amount of dead space. This effect is inversely proportional to the size of the patient being monitored.[44,58]

    6.1.2 The addition of the weight of a mainstream adapter can increase the risk of accidental extubation in neonates and small children.[58]

6.2 Sidestream

    6.2.1 The gas sampling rate from some sidestream analyzers may be high enough to cause auto-triggering when flow-triggering of mechanical breaths is used. This effect is also inversely proportional to the size of the patient.[58]

    6.2.2 The gas sampling rate can diminish delivered V_T in neonates and small patients while using volume targeted or volume controlled ventilation modes.[58]

CO_2 MV 7.0 LIMITATIONS OF PROCEDURE OR DEVICE

Capnography, when performed using a device calibrated and operated as recommended by the manufacturer, has few limitations. It is important to note that although the capnograph provides valuable information about the efficiency of ventilation (as well as perfusion), it is not a replacement or substitute for assessing the P_{aCO_2}.[4,41,59-61] The difference between P_{ETCO_2} and P_{aCO_2} increases as dead-space volume increases.[62] In fact, the difference between the P_{aCO_2} and P_{ETCO_2} varies in the same patient over time.[43,63-65] Alterations in breathing pattern and V_T may introduce error into measurements designed to be made during stable, steady-state conditions.[51,52,66] Interpretation of results must take into account the stability of physiologic variables such as minute ventilation, V_T, cardiac output, $\dot{V}/\dot{Q}$, and CO_2 body stores. Certain situations may affect the reliability of the capnogram. The extent to which the reliability is affected varies somewhat among types of devices. Limitations include:

7.1 The composition of the respiratory gas may affect the capnogram (depending on the measurement technology incorporated).

    7.1.1 The infrared spectrum of CO_2 has some similarities to the spectra of both oxygen and nitrous oxide.[50] A high concentration of either oxygen or nitrous oxide, or both, may affect the capnogram, so a correction factor should be incorporated into the calibration of any capnograph used in such a setting.[59]

    7.1.2 The reporting algorithm of some devices (primarily mass spectrometers) assumes that the only gases present in the sample are those that the device is capable of measuring. When a gas that cannot be detected by the mass spectrometer (such as helium) is present, the reported CO_2 values are incorrectly elevated in proportion to the concentration of the gas present.[4,67]

7.2 The breathing frequency may affect the capnograph. A high breathing frequency may exceed the capnograph's response capabilities. The presence of high airway resistance, respiratory rate, or inspiratory-to-expiratory ratio may decrease the accuracy of the measurement obtained from a sidestream capnograph, compared to a mainstream capnograph.[68,69] In addition, a breathing frequency > 10 breaths/min affects different capnographs differently.[67]

7.3 Contamination of the monitor or sampling system by secretions or condensate, a sample tube of excessive length, too high a sampling rate, or obstruction of the sampling chamber can lead to unreliable results.

7.4 Use of filters between the patient airway and the capnograph's sampling line may lead to artificially low P_{ETCO_2} readings.[31,70]

7.5 The sensitivity for confirmation of endotracheal intubation by color change could range from 67% to 72%.[71]

7.6 Clinical conditions associated with false negative readings include:

7.6.1 Low cardiac output may cause a false negative result when attempting to verify endotracheal tube position in the trachea.[72]

7.6.2 During CPR a positive test confirms placement of the ETT within the airway, whereas a negative test indicates either esophageal intubation or airway intubation with poor or absent pulmonary blood flow and requires an alternate means of confirmation of tube position.[73-75]

7.6.3 When the endotracheal tube is in the pharynx and when antacids and/or carbonated liquids are present in the stomach, a false negative reading may be present. However, the waveform does not continue during subsequent breaths.[76]

7.6.4 Elimination and detection of CO_2 can be dramatically reduced in patients with severe airway obstruction and pulmonary edema.[77]

7.7 Clinical conditions associated with false positive readings include:

7.7.1 Colorimetric CO_2 detectors may give a false positive if contaminated with acidic or CO_2-filled gastric content, intratracheal medications such as epinephrine, extreme humidity, or the presence of trichloroethylene or chloroform anesthetics. Most require at least 6 breaths before a decision can be made.[6,78]

7.7.2 Detection of CO_2 in expired gas after esophageal intubation as a result of prior bystander mouth-to-mouth ventilation may result in a false positive reading.[79]

7.7.3 A transient rise in P_{ETCO_2} after sodium bicarbonate administration is expected, but should not be misinterpreted as an improvement in quality of CPR or a sign of return of spontaneous circulation.[5]

7.8 Inaccurate measurement of expired CO_2 may be caused by leaks or other clinical circumstances preventing collection of expired gases,[80] including:

7.8.1 Leaks in the ventilator circuit.

7.8.2 Leaks around the tracheal tube cuff, an uncuffed tube, or the mask, including LMA.

7.8.3 Bronchopleural fistula.

7.8.4 Dialysis or extracorporeal life support.

CO$_2$ MV 8.0 ASSESSMENT OF NEED

Capnography is considered a standard of care during general anesthesia. The American Society of Anesthesiologists has suggested that capnography be available for patients with acute ventilatory failure on mechanical ventilatory support.[81] The American College of Emergency Physicians recommends capnography as an adjunctive method to ensure proper endotracheal tube position.[75] The 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care recommend capnography to verify endotracheal tube placement in all age groups.[6] Assessment of the need to use capnography with a specific patient should be guided by the clinical situation. The patient's primary cause of respiratory failure and the severity of his or her condition should be considered.

CO$_2$ MV 9.0 ASSESSMENT OF OUTCOME

Results should reflect the patient's condition and should validate the basis for ordering the monitoring. Documentation of results (along with all ventilatory and hemodynamic variables available), therapeutic interventions, and/or clinical decisions made based on the capnogram should be included in the patient's chart.

CO$_2$ MV 10.0 RESOURCES

10.1 Equipment: the capnograph and accessories (eg, airway adapter, sampling tube, depending on capnograph). The capnograph should be calibrated as recommended by the manufacturer.

10.2 Personnel: licensed or credentialed respiratory therapists or individuals with similar credentials (eg, MD, RN) who have the necessary training and demonstrated skills to correctly calibrate and evaluate the capnograph, assess the patient and the patient-ventilator system, and the ability to exercise appropriate clinical judgment.

CO$_2$ MV 11.0 MONITORING

11.1 During capnography the following should be considered and monitored:

11.1.1 Ventilatory variables: V_T, respiratory rate, PEEP, ratio of inspiratory-to-expiratory time, peak airway pressure, and concentrations of respiratory gas mixture.[3,38,44,72,82]

11.1.2 Hemodynamic variables: systemic and pulmonary blood pressure, cardiac output, shunt, and $\dot{V}/\dot{Q}$ imbalances.[23,41,66]

CO$_2$ MV 12.0 FREQUENCY

Capnography (or, at least, capnometry) should be available during endotracheal intubation.[14,19,83] Capnography is not indicated for every mechanically ventilated patient; however, when it is used, the measurement period should be long enough to allow determination of the P_{aCO_2}-P_{ETCO_2} difference, to note changes in the P_{aCO_2}-P_{ETCO_2} difference

as a result of therapy, and to allow interpretation of observed trends.

CO$_2$ MV 13.0 INFECTION CONTROL

No specific precautions are necessary, although standard precautions (as described by the Centers for Disease Control and Prevention)[27] and precautions designed to limit the spread of tuberculosis[80,84] should always be implemented during patient care.

13.1 Reusable mainstream sensors should be subjected to high-level disinfection between patients, according to the manufacturer's recommendations.

13.2 The external surface of the monitor should be cleaned as needed, according to manufacturer's recommendations.

CO$_2$ MV 14.0 RECOMMENDATIONS

The following recommendations are given based on the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) scoring system[85,86]:

14.1 Continuous waveform capnography is recommended in addition to clinical assessment as the most reliable method of confirming and monitoring correct placement of an endotracheal tube. (1A)

14.2 If waveform capnography is not available, a non-waveform exhaled CO_2 monitor in addition to clinical assessment is suggested as the initial method for confirming correct tube placement in a patient in cardiac arrest. (2B)

14.3 P_{ETCO_2} is suggested as a method to guide ventilator management. (2B)

14.4 Continuous capnometry during transport of a mechanically ventilated patient is suggested. (2B)

14.5 Capnography is suggested to identify abnormalities of exhaled air flow. (2B)

14.6 Volumetric capnography is suggested to assess CO_2 elimination and V_D/V_T to optimize mechanical ventilation. (2B)

14.7 Quantitative waveform capnography is suggested in intubated patients to monitor CPR quality, optimize chest compressions, and detect return of spontaneous circulation during chest compressions or when rhythm check reveals an organized rhythm. (2C)

CO$_2$ MV 15.0 CLINICAL PRACTICE GUIDELINE IDENTIFYING INFORMATION AND AVAILABILITY

15.1 Adaptation
Original publication: Respir Care 1995;40(12):1321-1324.

15.2 Guideline Developers
American Association for Respiratory Care Clinical Practice Guidelines Steering Committee.
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