Clinical Monograph

CO_2 Detection: Intubation and Cardiopulmonary Resuscitation

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Clinical Education

INTRODUCTION

Nearly three million intubations are performed outside of the operating room in the United States each year. A review of literature reveals that approximately 1% to 24% of intubation attempts may result in esophageal intubations, which carry a significant risk of morbidity and mortality. Traditional methods of assessing endotracheal tube placement, including assessment of breath sounds and chest movement, are not always reliable. The most reliable and easiest method for determining the adequacy of endotracheal tube placement is the detection of carbon dioxide in the patient's exhaled gas.

The purpose of this monograph is to review the incidence and causes of esophageal intubation and to discuss a carbon dioxide detection strategy that can decrease the morbidity and mortality associated with esophageal intubations. The physiology of carbon dioxide production and elimination will be reviewed and discussed in relation to carbon dioxide detection. This monograph will also include a discussion of carbon dioxide detection issues during cardiopulmonary arrest and cardiopulmonary resuscitation.

BEHAVIORAL OBJECTIVES

By the end of this session, the learner will be able to:

1. Identify three commonly used techniques for assessing endotracheal tube placement and reasons why these techniques may be incorrect in verifying endotracheal intubation.

2. State the value of carbon dioxide detection in assessing proper endotracheal tube placement.

3. State the effect of cardiopulmonary arrest on end-tidal carbon dioxide.

4. Review the color change response of the *Easy Cap II®, Pedi-Cap®,* and CO_2 Plus CO_2 detectors and appropriate clinical interventions for each color range.

A recent review of literature reveals that from 1% to 24% of emergency intubations result in esophageal intubations.[1,2,3,4] The most common consequences of undetected esophageal intubation are death or permanent brain damage. In an analysis of 1541 closed anesthesia malpractice claims, esophageal intubations accounted for 18% of the 522 respiratory claims. Of particular importance, 98% of these esophageal intubations resulted in death or permanent brain damage, and 82% of the claims were paid, with judgements as high as $3.4 million.[5]

Successful endotracheal intubation requires the placement of orotracheal or nasotracheal tubes directly into the trachea. Endotracheal intubation outside of the operating room commonly occurs under emergency circumstances marked by less-than-ideal conditions. Intubation attempts may fail to result in tracheal placement for several reasons. The patient may have a difficult airway, because of anatomic abnormalities or injury of the head and neck. Airway edema may be present, occuring as a result of respiratory disease or prior airway instrumentation. Excessive blood and secretions in the upper airway may interfere with the ability to visualize the vocal cords. The environmental conditions associated with emergency intubations, including adverse weather, lighting, noise, and equipment resources, may also increase the difficulty of intubations. The pediatric and obese patient may present difficult intubation challenges.

Several traditional methods of assessing accurate endotracheal tube placement have demonstrated incidences of fallibility. Potential causes of error from relying on these methods include:

Method	Potential Source of Error
direct visualization of the endotracheal tube through the vocal cords	unable to visualize due to anatomy or trauma; excessive blood and secretions in the upper airway; inadvertent tube movement during position change or during taping procedures[4,6,7,8,9,10]
observation of chest wall movement	rigid chest wall, obesity, large breasts; chest wall movement has been documented with esophageal tube placement[6,11,19]
auscultation of breath sounds	"normal" breaths sounds documented with esophageal tube placement; movement of air through esophageal tube may be similar to true breath sounds[6,11,12,13]

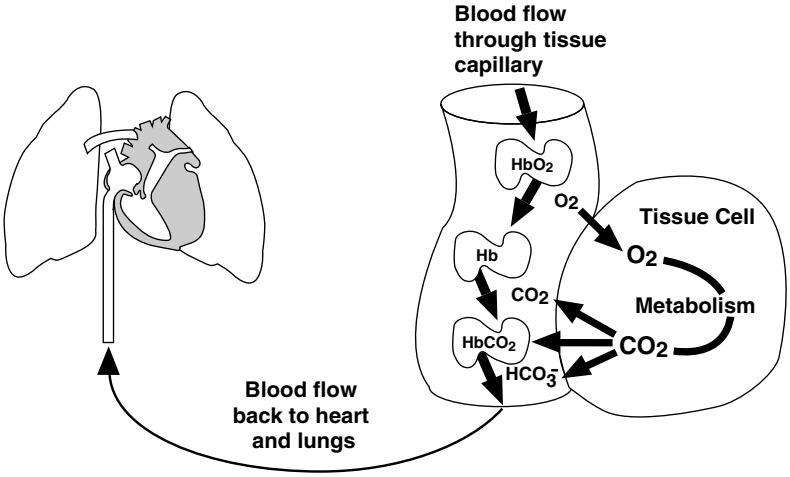
Method (continued)	Potential Source of Error
epigastric auscultation and observation	breath sounds can be transmitted to the epigastric area, especially in a thin patient; gastric distension can be difficult to distinguish and may be attributed to mask ventilation prior to intubation[9,11]
presence of exhaled tidal volumes	measurable tidal volumes have been documented with esophageal intubation[14]
assessment of reservoir bag compliance	repeated filling and emptying of stomach with esophageal intubation can cause breathing bag to inflate and deflate[9,11,15]
endotracheal tube cuff maneuvers	distinction in sounds from air leak around deflated tube cuff does not clearly vary with tracheal and esophageal tube positions[11,15]
observation of condensation in the endotracheal tube	condensation can occur with esophageal tube placement[6]
chest radiography	interpretative error has been documented; not always available and could delay diagnosis[6,16]

Even if the typical assessment techniques listed above suggest proper endotracheal tube placement, the tube may be inadvertently dislodged during patient motion or transport.

The most reliable and easiest method for determining the adequacy of endotracheal tube placement is the detection of carbon dioxide in the exhaled patient gas.[6,9] Carbon dioxide is produced by the lungs and exhaled through the trachea. Carbon dioxide is not normally produced in the stomach, but it may be present if the patient has consumed carbonated beverages or certain medications, or if the carbon dioxide that exits from the lungs has been transported into the esophagus during ventilation. If the endotracheal tube is inadvertently placed into the esophagus, a small amount of carbon dioxide may be present, but this is rapidly eliminated within the first few breaths.[17] A carbon dioxide detection device may detect the presence of carbon dioxide immediately after intubation, but should cease to do so after about the first six breaths. A failure to detect carbon dioxide after this time suggests esophageal intubation in the patient with adequate blood flow to the lungs.

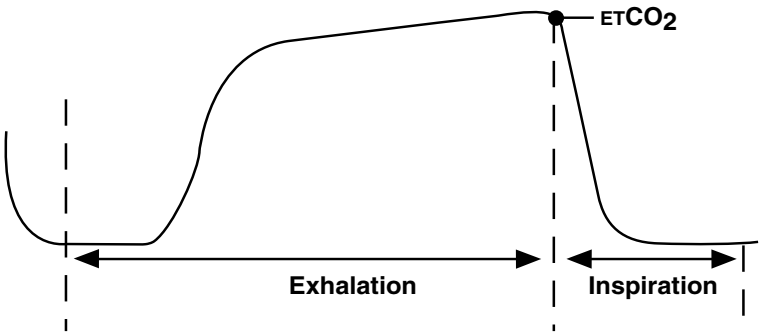
CARBON DIOXIDE: PHYSIOLOGY

Carbon dioxide (CO_2) is a waste product of normal cellular metabolism. CO_2 leaves the cells and is carried by the venous blood to the heart and lungs. Once CO_2 reaches the lungs, it is eliminated in the process of exhalation. In order for CO_2 to be effectively eliminated from the body, there must be adequate blood flow to the lungs, adequate gas exchange across the alveolar-capillary membrane, and adequate ventilation of the lungs to "blow off" the CO_2.



The amount of CO_2 that is elimated from the lungs can be measured with the placement of a CO_2 sensor at the patient's airway. The amount of CO_2 detected at the end of exhalation is referred to as end-tidal CO_2, or $ETCO_2$. This end-tidal value normally falls within a range of 35 to 45 mmHg. During inspiration, when the patient normally breathes in CO_2 free gas, no CO_2 is normally detected, and the $ETCO_2$ returns to zero.

$ETCO_2$ Waveform



■ **Decreased blood flow and $ETCO_2$**

If venous blood flow to the lungs is normal, CO_2 is transported to the lungs where it can be eliminated during exhalation. When little or no blood returns to the lungs, such as may occur with pulmonary embolism, hypovolemia, and hypotension, little carbon dioxide may be carried back to the lungs. Consequently, the concentration of CO_2 in the exhaled gas will be decreased below the normal range of 35 to 45 mmHg. This drop in end-tidal CO_2 will depend on the degree to which this blood flow back to the lungs has been compromised. For example, a small pulmonary embolism may decrease end-tidal CO_2 by a small amount, whereas a large pulmonary embolism can decrease end-tidal CO_2 significantly. Electronic or disposable CO_2 detection devices will show these lower-than-normal carbon dioxide levels in exhaled gas.

■ Cardiac arrest, CPR, and ETCO$_2$

During cardiac arrest, the heart is unable to pump blood throughout the body. CO_2 continues to be produced by the tissues, but it is not transported to the lungs in the venous blood. CO_2 is not normally present in the exhaled gases during non-cardiopulmonary resuscitation (CPR) cardiac arrest.

CPR includes the application of chest compressions to mechanically transport oxygenated blood to the tissues and carbon dioxide back to the lungs where it can be exhaled. With effective compressions, it is possible to detect lower-than-normal CO_2 concentrations in exhaled gases. These concentrations may range from 0.5% to 2.5%.[2,18] Therefore, CO_2 detection devices may provide useful information about the effectiveness of cardiopulmonary resuscitation. With return of spontaneous circulation that occurs with successful resuscitation efforts, normal ETCO$_2$ concentrations are commonly detected.[2,3,18,19]

A CO_2 measurement device can be placed at the end of the endotracheal tube to determine the presence of CO_2 throughout the breathing cycle. With proper placement of the endotracheal tube into the trachea, CO_2 should be detected at the end of exhalation. CO_2 will normally not be detected after six breaths if the tube is placed in the esophagus. CO_2 is not normally detected during inspiration since the patient is usually breathing CO_2 free gas.

CO_2 detection systems may be continuous, electronic devices, or they may be a disposable device designed for short-term monitoring. Electronic CO_2 detection systems typically use infrared light to determine the CO_2 concentration in exhaled gases. A disposable CO_2 detector demonstrates color changes in the presence of CO_2. Each of these CO_2 detectors will be examined in more detail.

■ Electronic CO_2 Detection

Electronic CO_2 detection systems may be used to monitor the presence of exhaled CO_2 on a short- or long-term basis. A CO_2 sensing device may be placed directly on the patient's airway, or the patient's gases may be diverted away from the airway to the CO_2 sensor.

The most common type of CO_2 detector uses infrared light to determine the concentration of CO_2 in the exhaled gas. Infrared light is used because it is absorbed by CO_2, and the amount of light that is absorbed is translated into a CO_2 measurement.

Some electronic CO_2 detection technologies may provide a capnograph, or CO_2 waveform, along with continuous numeric information about the concentration of CO_2. Other technologies may provide semiquantitative information about the CO_2 concentration at the end of exhalation.

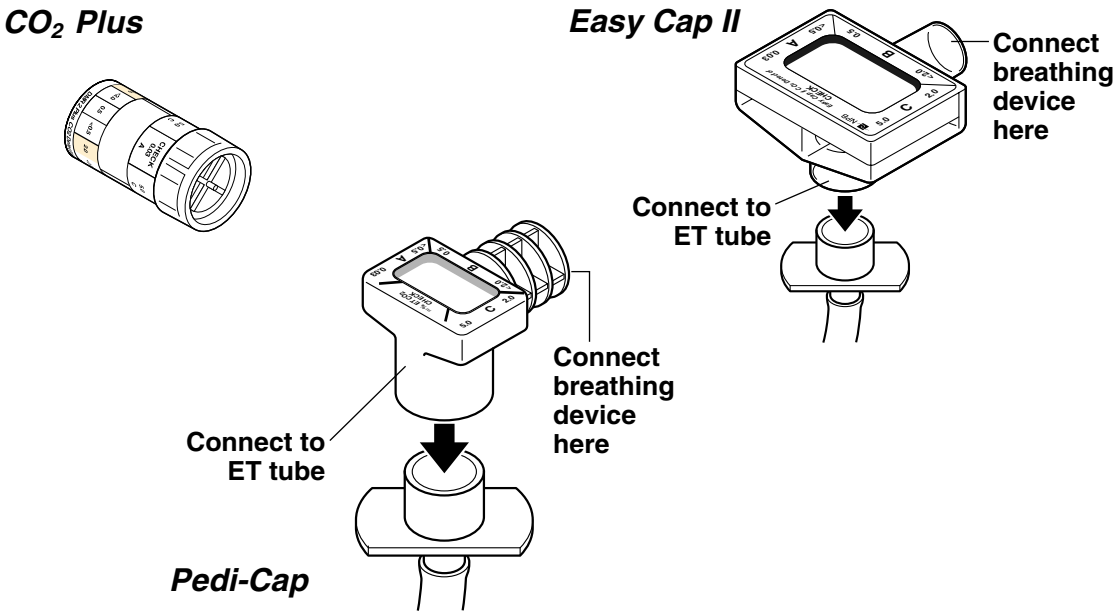
Electronic CO_2 detection and monitoring systems are commonly used at the bedside in the inpatient setting, whenever anesthesia is delivered, and during intrahospital transport of the patient.

■ *Colormetric* CO_2 Detectors

Colormetric CO_2 detectors are simple, reliable, and disposable CO_2 detection systems that are commercially available and can provide validation of the presence of CO_2 in a patient's exhaled gas. These products have broadened the capability to validate the presence of CO_2 after intubations in nearly any clinical situation.

These devices, commercially known as the *Easy Cap II* and *Pedi-Cap* $ETCO_2$ detectors, are disposable, lightweight devices that fit all standard airway connectors. These are placed onto the endotracheal tube during intubation and can reliably detect CO_2 on a breath-by-breath basis for up to two hours.

These CO_2 detectors contain a nontoxic chemical indicator that quickly responds to exhaled CO_2 by a reversible color change. The color changes from exhalation to inspiration as CO_2 levels rise and fall. The CO_2 detectors are normally purple in the absence of CO_2, change to tan or yellow in the presence of higher concentrations of CO_2, and return to purple during inspiration of gas that is normally free from CO_2.



The color on the CO_2 detectors will fall into one of three ranges depending on the CO_2 concentrations. These colors, and their associated ranges of CO_2, are as follows:

"A" range	Purple	approximately 0.03 to < 0.5% $ETCO_2$ (<4 mmHg*)
"B" range	Tan	approximately 0.5 to < 2% $ETCO_2$ (4 to < 15 mmHg*)
"C" range	Yellow	approximately 2 to 5% $ETCO_2$ (15 to 38 mmHg*)

* mmHg range for sea level

■ Interpreting Color Changes:

Color Range "A" (purple) during exhalation: When the endotracheal tube is incorrectly positioned in the esophagus, the CO_2 detector will remain purple during inspiration and exhalation. A continued purple color after six breaths in the patient with adequate blood flow indicates esophageal intubation. A continuous purple color may also occur during cardiac arrest without compressions, or with ineffective compressions, even if the trachea is correctly intubated.[20,21]

Both of these problems require immediate attention. An uncorrected, continuous purple color usually indicates that gas exchange is insufficient to support patient survival.

Color Range "B" (tan) during exhalation: During conditions where blood flow to the lungs is decreased, or when CO_2 production is decreased (hypocarbia), the CO_2 detectors may change to tan at the end of exhalation. The tan color may also initially appear during end-exhalation within the first six breaths if some CO_2 is present in the stomach, but after six more breaths have been delivered, any retained CO_2 will have been cleared. If the color changes to the purple range after six additional breaths have been delivered, two possibilities exist: the endotracheal tube may not be in the trachea or there is low blood flow to the lungs, such as occurs with cardiac arrest or inadequate chest compressions. If the color remains tan, the endotracheal tube is in the trachea, but the patient has decreased blood flow to the lungs or decreased CO_2 production.

Color Range "C" (yellow) during exhalation: If the trachea is properly intubated and blood flow to the lungs is adequate, the CO_2 detectors will change to a yellow color during exhalation. This rules out esophageal intubation and indicates that the lungs are being ventilated.

During cardiac arrest, a dramatic improvement in the CO_2 detectors' color (e.g., from the purple or tan range to the yellow range) indicates a large increase in $ETCO_2$. This usually signals the return of spontaneous circulation. The American Heart Association standards recommend confirming this by checking the carotid pulse.[22]

During cardiopulmonary arrest, blood that contains CO_2 is not returned to the lungs, so CO_2 is not eliminated during exhalation. The CO_2 detectors will remain purple during exhalation as well as inspiration, even if the trachea is correctly intubated. Appropriate clinical action should be taken to restore pulmonary blood flow.

During CPR with effective compressions, some blood should circulate back to the lungs, so some CO_2 should be eliminated during exhalation. The detector may turn to tan or possibly even yellow during effective CPR.[2,3,18,19] A change in rescuers during CPR has been associated with color changes from purple to tan if the new rescuer is delivering more effective compressions.[23]

If spontaneous circulation is restored as a result of effective CPR, the CO_2 detectors may turn yellow since CO_2 that has been built up in the tissues is suddenly returned to the lungs.

CO_2 DETECTOR DECISION TREE

The following decision tree highlights recommended clinical actions for various ranges of end-tidal CO_2. Connect the CO_2 detector to the endotracheal (ET) tube. After six full breaths, evaluate the CO_2 detector color.

■ Adequate Perfusion—Spontaneous Heartbeat

Color Range "A"

0.03% to < 0.5% $ETCO_2$
< 4 mmHg*

↓

ET tube not in trachea

↓

Reinsert tube

↓

Recheck using CO_2 detector

Color Range "B"

0.5% to < 2% $ETCO_2$
4 to < 15 mmHg*

↓

Retained CO_2 in esophagus or low perfusion or hypocarbia

↓

Deliver six more breaths

↓

Color remains tan

↓

ET tube in trachea with low perfusion or hypocarbia

Color Range "C"

2% to 5% $ETCO_2$
15 to 38 mmHg*

↓

ET tube in trachea†

↓

Secure tube

↓

Continue to observe color change

■ Poor Perfusion—Cardiac Arrest

Color Range "A"

0.03% to < 0.5% $ETCO_2$
< 4 mmHg*

↓

ET tube *not* in trachea or inadequate perfusion (Ineffective CPR)

↓

Check if ET tube is through vocal cords

NO
ET tube not in trachea

↓

Reinsert tube
Recheck using CO_2 detector

YES
ET tube in trachea with inadequate perfusion

↓

Take appropriate clinical action

Color Range "B"

0.5% to < 2% $ETCO_2$
4 to < 15 mmHg*

↓

Retained CO_2 in esophagus or low perfusion

↓

Deliver six more breaths

↓

Color remains tan

↓

ET tube in trachea with low perfusion

Color Range "C"

2% to 5% $ETCO_2$
15 to 38 mmHg*

↓

ET tube in trachea†

↓

Secure tube

↓

Continue to observe color change

* mmHg range for sea level
† May also occur if the ET tube is in the posterior pharynx and ventilation is occuring.

The CO_2 detectors can provide continuous information about the presence of CO_2 in the exhaled gas for up to 2 hours. Reflux of gastric contents, secretions, or fluids can produce a permanent, patchy yellow or white color on the detector, and the detector must be replaced to ensure reliable readings.

Some drugs that are delivered through the trachea, including epinephrine, can also cause the detector to turn a permanent, patchy yellow or white color if they come in contact with the color indicator on the CO_2 detector. It is easy to recognize this because the detector does not turn purple during inspiration. When administering a drug through the endotracheal tube, remove the CO_2 detector and then administer the drug. Reattach the detector after the risk of reflux has passed.

Certain drugs can affect the actual end-tidal CO_2 value. Intravenous sodium bicarbonate can produce a temporary increase in end-tidal CO_2, which will be reflected by the CO_2 detector as a temporary movement towards the tan or yellow range.[18] However, this change disappears after a few minutes and may be less intense than that seen with the return of spontaneous heartbeats.

Additionally, high-dose intravenous epinephrine (for example, 0.2 mg/kg) has been shown to decrease end-tidal CO_2.[24] Therefore, it would be expected to produce a corresponding color change in the CO_2 detector.

Contamination of the CO_2 detector with particulate matter (i.e., vomitus, activated charcoal) may increase airway resistance and affect patient ventilation.

CO_2 detection devices should be used whenever patients are intubated. After proper tube placement is validated, they should continue to be used to verify the presence of CO_2 in exhaled gases. Disposable CO_2 detection devices can be used in many clinical situations. They are commonly stocked on code carts, on emergency transport vehicles and in intubation kits, and in special procedure areas.[25,26,27]

Many emergency transport services and institutions have established protocols that require clinicians to check for the presence of CO_2 in exhaled gas after intubation, and in the management and transportation of all intubated patients.

With consistent use of CO_2 detection devices for emergency intubations, the unfortunate incidence of esophageal intubations, and their associated morbidity and mortality, can be reduced.

POST TEST

1. Of the following methods for ruling out esophageal intubation, which method is regarded as the most reliable?

   a. Assessment of bilateral breath sounds.

   b. Presence of condensation in the endotracheal tube.

   c. Assessment of reservoir bag compliance.

   d. Presence of CO_2 in the patient's exhaled gas.

2. Immediately after intubating your patient, you notice small amounts of CO_2 in your patient's exhaled gas. Which of the following is a true statement:

   a. You can be certain that the endotracheal tube is positioned in the trachea.

   b. If a small amount of CO_2 is still present after six breaths, you have an esophageal intubation with retained CO_2 in the stomach.

   c. If CO_2 is still present after 12 breaths, the endotracheal tube is in the trachea.

   d. Your patient is probably about to have a cardiac arrest.

3. You arrive on the scene and find a patient who appears to be in complete cardiac arrest. You immediately intubate the patient and initiate chest compressions, but your CO_2 detector remains purple in color, even during exhalation. Which of the following statements most accurately reflects your patient's situation?

   a. Your patient shows poor prognostic signs of recovery and you should discontinue resuscitation.

   b. The trachea is definitely not intubated.

   c. Compressions are definitely not effective.

   d. Your patient must be carefully assessed because the trachea may not be intubated and/or compressions may be ineffective for circulation of blood.

4. A sudden change in color on the CO_2 detector from tan to yellow during cardiac compressions may indicate:

   a. Dislocation of the endotracheal tube into the esophagus.

   b. Ineffective chest compressions.

   c. Return of spontaneous circulation.

   d. Ensured survival of the patient.

POST TEST ANSWERS

1. (d) Presence of CO_2 in the patient's exhaled gas.

2. (c) If CO_2 is still present after 12 breaths, the endotracheal tube is in the trachea.

3. (d) Your patient must be carefully assessed because the trachea may not be intubated and/or compressions may be ineffective for circulation of blood.

4. (c) Return of spontaneous circulation.

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TABLE OF CONTENTS

Introduction 1

Behavioral Objectives 2

Esophageal Intubation: Risk, Consequences, and Causes 3

Carbon Dioxide: Physiology 5

Carbon Dioxide: Detection and Measurement 7

Carbon Dioxide Detection During Cardiac Arrest
and Cardiopulmonary Resuscitation 10

CO_2 Detector: Decision Tree 11

CO_2 Detection: Clinical Considerations 12

Clinical Applications 13

Post-Test 14

Post-Test Answers 15

References 16

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