Confirmation of Endotracheal Tube Placement: A Miniaturized Infrared Qualitative CO_2 Detector

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Study objectives: *A miniaturized, infrared, solid-state, end-tidal CO_2 detector was used to confirm emergency endotracheal tube (ETT) placement.*

Design: *This prospective, clinical study used a miniature, infrared, solid-state end-tidal CO_2 detector to confirm ETT placement in an acute setting.*

Setting: *The ICU, emergency department, and hospital floor.*

Type of participants: *There were 88 consecutive adult patients requiring 100 emergency intubations.*

Measurements and main results: *The indication for airway intervention was considered urgent in 79% and under arrest conditions in 21%. The mean number of intubation attempts was 1.83 (range, one to five) with difficulty of intubation of 6.48 and confirmation of 7.75, on a linear scale from 0 (lowest) to 10 (highest). Determination of ETT position revealed intratracheal intubation in 96% and esophageal intubation in 4%. Placement was confirmed by direct visualization or radiography in all cases. Sensitivity and specificity for ETT localization was 100% ($P < .0001$).*

Conclusion: *This hand-held infrared capnometer reliably confirms ETT placement under emergency conditions. [Vukmir RB, Heller MB, Stein KL: Confirmation of endotracheal tube placement: A miniaturized infrared qualitative CO_2 detector. Ann Emerg Med July 1991;20:726-729.]*

INTRODUCTION

Airway control has been described since 3600 BC, when tracheostomy was used by the Egyptians.[1] Modern interventions include the introduction of endotracheal tubes (ETTs) for anesthesia by MacEwen in 1880,[2] but the first clinical use of endotracheal intubation for airway control was advanced by Jackson in 1907.[3]

Endotracheal intubation is associated with an approximate complication rate of 26%.[4] Perhaps the most catastrophic outcome of this procedure is unrecognized esophageal intubation. Fully 15% of anesthesia-related accidents resulting in brain damage or death are the result of esophageal intubation.[5] This hazard is illustrated by the statement that "even a conscientious, careful anesthesiologist may be unable to differentiate tracheal from esophageal intubation by commonly employed methods."[6] Accidental esophageal intubation has been reported in even well-controlled anesthesia settings as well as in the prehospital realm[7-9] where ineffective airway management may be the most important factor contributing to out-of-hospital deaths.[10] In a study of paramedic intubations of 799 patients, Stewart et al found a 9.5% complication rate, with 1.8% resulting in esophageal misplacement.[11]

This study used a standard modality for confirmation of ETT position – detection of end-tidal CO_2 – under rigorous conditions to confirm placement in airway emergencies, including cardiopulmonary arrest settings.

MATERIALS AND METHODS

This prospective, nonrandomized study used a miniaturized qualitative capnometer to confirm ETT position by the presence of CO_2 in the ventilatory cycle. Minicap® III (Mine Safety Appliances Co, Pittsburgh, Pennsylvania) is a solid-state, infrared spectrophotometer featuring mainstream

FIGURE. *Minicap™ III.*

sampling with a sensitivity of 0.50, vol% CO_2 (Figure). This instrument costs approximately $900; is battery operated, portable, and compact; weighs 14.3 oz; measures 5.75 × 2.75 × 1.75 cm; and has a belt clip similar to a pager. Minicap™ III operates as an apnea monitor with an audible alarm and red warning light indicating loss of respiration after an adjustable interval of ten to 60 seconds. Respiration is sensed and then indicated as a tone and green visual display for each ventilation cycle. The sensor is equipped with a band-pass filter to prevent misinterpretation of anesthetic gas mixtures and is fitted with a disposable plastic mainstream adapter. The device is available for instant use without calibration or warm-up period.

The patient group included those requiring intubation by nasal, oral, or tracheal route for the purpose of airway protection, oxygenation, ventilation, or confirmation of prior ETT placement. All patients requiring emergency intubations by critical care physicians in the ICU, emergency department, and medical-surgical ward were eligible for inclusion; there were no exclusion criteria (ie, patients in cardiopulmonary arrest were eligible). The study was approved by the Biomedical Institutional Review Board of the University of Pittsburgh. The doctrine of implied consent was used for this noninvasive monitoring technique.

Information was recorded in a questionnaire format by each physician using the device and subsequently compiled by the investigators. Not all critical care physicians used the device on all emergency intubations, but every recorded use of the device was included. The difficulty of intubation and confirmation was estimated by the operator using an 11-point Likert scale graded from 0 (least difficult) to 10 (most difficult). Complications between groups were compared using Fisher's exact test with an α level set at .05 to evaluate differences in ETT position determined by Minicap™ III and standard confirmation techniques including clinical examination, direct visualization, and radiography.

RESULTS

The study involved 100 cases in 88 patients recorded during a six-month period. One case was excluded when the device correctly determined ETT position but then failed to sense when the detector connection was altered. Normal function returned with adjustment of the cord. Seventy-nine percent of patients enrolled were in the ICU, 11% in the ED, and 10% on the hospital floor. Patients were intubated primarily for respiratory distress in 31% with the intubation thought to be urgent in 79% and emergent, specifically cardiac or traumatic arrest, in 21% (Table 1). The route of intubation was oral in 92%, nasal in 5%, and through an existing tracheostomy in 3%.

The mean number of intubations was 1.83 (range, one to five) with difficulty of intubation estimated at 6.48 (range, 1 to 10) and confirmation at 7.75 (range, 1 to 10). All cases were confirmed with direct visualization, chest radiograph, or both. Other methods of confirmation, including auscultation and pulse oximetry, were common (Table 1).

The ETT position was found to be tracheal in 96% and esophageal in 4% as determined by capnometry using Minicap™ III (Table 2). These positions were confirmed by standard methods, direct visualization or chest radiograph, in all cases. Thus, the sensitivity and specificity for ETT localization were both 100% (Table 1) with no significant difference in ETT position determined by capnometry compared with standard methods ($P > .05$).

TABLE 1. *Indication and methods of confirmation of intubation*

Indication	% of Patients
Respiratory distress	31
Airway protection	27
ETT position	18
Cardiac arrest	17
Traumatic arrest	4
ETT replacement	3
Confirmation	
Chest auscultation	98
Epigastric auscultation	92
Chest excursion	87
Chest radiograph	82
Direct visualization	79
Pulse oximetry	67
ETT condensation	36
Arterial blood gas	4

DISCUSSION

ETT position is suggested but not confirmed by a number of techniques. The general guidelines for an ideal method are that 1) the test should work for difficult intubations; 2) positive tests must be unequivo-

TABLE 2. *Comparison of results*

	Minicap® III	
ETT Position	**Tracheal**	**Esophageal**
Tracheal	96 True-positive (100%)	0 False-negative (0%)
Esophageal	0 False-positive (0%)	4 True-negative (100%)

cal; 3) esophageal intubation must always be detected; and 4) clinicians must understand the test.[12]

Techniques for clinical evaluation of ETT position include direct visualization,[8] ambu-bag compliance,[8,13] auscultation of breath sounds,[8,13,14] symmetrical chest excursion,[13] auscultation of epigastric sounds,[8,15] vital sign change,[8] cyanosis or hypoxemia,[16] tracheal cuff palpation,[17-19] tactile digital palpation,[20] chest compression,[8] flexible fiberoptic catheter bronchoscopy,[21,22] suction esophageal detection device,[23,24] pulse oximetry,[15,25-28] lighted stylet,[29] cuff seal volume,[30] chest radiograph,[31-33] ultrasound,[34] exhaled tidal volume,[7] tube condensation,[8] gastric contents,[15] colorimetric end-tidal CO_2 detector,[35] and end-tidal CO_2 measurement.[15] Each of these techniques has been suggested to confirm ETT position; although they vary in accuracy, some conclusions can be inferred.

Clinical testing cannot be relied on, and the only unequivocal signs of correct tube placement are direct visualization, including recheck laryngoscopy, fiberoptic bronchoscopic identification of endotracheal lumen, and detection of physiologic CO_2 concentration of exhaled gas.[24] However, each of these gold standards has been associated with some limitation. Direct visualization may be the most reliable technique, although it is not always anatomically possible.[36] The ETT can be accidentally dislodged, and 1.9 cm of change in ETT position with normal head flexion or extension has been documented.[37] Radiographic assessment has been associated with delayed diagnosis resulting in prolonged esophageal intubation.[31] Bronchoscopy requires special apparatus and ability and is time consuming. Pulse oximetry may be limited by a delay in the detection of oxyhemoglobin desaturation, especially with preoxygenation, as well as by inability to sense during a low-flow state.[25]

CO_2 monitoring "comes closest to being a fail-safe monitor for most problems that cause anoxia and death."[38] The earliest experiments in CO_2 measurement were performed by Tyndall (1859) and Luft (1943), who developed the principle of capnometry by which CO_2 is measured by infrared absorption.[39] Primitive attempts at crude CO_2 measurement were made in the anesthesia suite by the barium hydroxide agglutination reaction[40] and the "Einstein CO_2 detector," which was capable of sensing 4 to 6 vol% CO_2.[41]

Modern CO_2 measurement is accomplished by two methods. Mass spectroscopy requires a centralized system suited for anesthesia and intensive care settings. Expired gas is sampled and examined for CO_2 as well as other volatile gases. This mode is the current standard. However, this method requires calibration and is costly -- about $60,000 for an average system.[42] End-tidal CO_2 measurement is based on the absorption of infrared light of 4.3-μm wavelength by the CO_2 molecule compared with a CO_2-free reference sample.[39] Sampling occurs through a sidestream system, which requires gas removal, is prone to contamination, and is used for mass spectroscopy and some capnography. Mainstream detectors place the sensor directly into the airway circuit, offer less contamination, and are featured in capnographs and capnometers. A band filter is featured to screen out other anesthetic gases.

The CO_2 concentration can be displayed in either qualitative, with an arbitrary CO_2 sensitivity, or quantitative fashion. Quantitative display includes capnometry, which yields a numerical display of CO_2 concentration, and capnography, which yields a real-time graphic waveform.[39] Ventilation is thus measured as end-tidal CO_2 that approximates $PaCO_2$ to within 2 to 6 mm Hg in normal lungs.[43] Expired CO_2 is determined by 1) production, dependent on metabolism and varying with temperature and muscle tone; 2) transport, dependent on circulation and varying with pulmonary perfusion; and 3) elimination, dependent on airway and respiratory mechanism integrity.[39]

The premise that with intact pulmonary circulation CO_2 is present in tracheal but not esophageal gas efflux is thus a reliable method of detecting ETT placement. Presence of CO_2 indicates tracheal intubation, and absence of CO_2 indicates esophageal intubation, circulatory arrest, technical malfunction, circuit disconnection, or intraluminal/extraluminal tube obstruction.[44,45]

A false-positive result, or an esophageal tube that is determined to be endotracheal, can occur theoretically in the setting of mask ventilation causing gastric insufflation of CO_2-containing expired gas. Trends noted during studies of esophageal intubation reveal that the volume of gastric CO_2 expired is lower, usually less than 0.7 vol% CO_2.[14,27] The waveform can initially appear normal but dissipates with successive ventilations (three to six),[44,46] even under the influence of carbonated beverage consumption.[44,47]

A false-negative result, or an endotracheal tube determined to be esophageal, can occur in a low pulmonary blood flow state, specifically, cardiac arrest. However, a correlation between end-tidal CO_2 and cardiac output has been demonstrated during CPR[48] with return of circulation.[49] Thus, end-tidal CO_2 monitoring is feasible during cardiac arrest and has even been suggested as a monitor of CPR efficacy.[50]

Recent clinical trials that have examined portable devices for confirmation of ETT placement should be scrutinized for two significant points – the prevalence of arrest patients studied and the incidence of false-negative findings that would result in misinterpretation of intratracheal position as equivocal or esophageal in a low perfusion state. In a controlled trial of 62 patients, Goldberg et al found a colorimetric device (sensitivity, 0.03 to 5 vol% CO_2) to be accurate in spontaneously breathing patients with one case (1.6%) of equivocal position that resolved with proper ETT cuff inflation.[51]

Studies performed by Ornato et al,[52] Bhende et al,[53] and Gerard et al[35] that included arrest patients in prehospital and hospital settings have demonstrated false-negative rates of 23.6% (17 of 72), 18.2% (two of 11), and 31.4% (11 of 35), respectively. Thus, under the most rigorous testing conditions, the colorimetric detector, although effective in patients with spontaneous respirations, has limited sensitivity for detecting intratracheal intubations in the arrest population.

However, in this study, Minicap III had no false-negative results in arrest patients (21 of 100) with low-flow states up to a maximum of 65 minutes. Respiratory variation did vary with CPR efficacy in several cases. This minimal sensitivity for CO_2 detection was not complicated by false-positive results in the four cases of esophageal intubation. An acknowledged difficulty with all such studies performed in actual patient care settings is the small number of esophageal intubations available for comparison. Finally, we have noted a problem with infrared detection of CO_2 in cold weather (less than 0 C), and the device is not currently recommended in the field environment under such conditions.[54]

CONCLUSION

Portable qualitative capnometry using the Minicap™ III is a sensitive and specific method of confirming endotracheal tube placement in an emergency in-hospital setting.

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