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Experimental paper

Endotracheal tube placement confirmation: 100% sensitivity and specificity with sustained four-phase capnographic waveforms in a cadaveric experimental model☆

Salvatore Silvestri[1], Jay G. Ladde[2], James F. Brown*[,3], Jesus V. Roa[3], Christopher Hunter[4], George A. Ralls[4], Linda Papa[5]

Department of Emergency Medicine, Orlando Regional Medical Center, 86 West Underwood Street, Suite 200, Orlando, FL 32806, United States

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ABSTRACT

Background: Waveform capnography is considered the gold standard for verification of proper endotracheal tube placement, but current guidelines caution that it is unreliable in low-perfusion states such as cardiac arrest. Recent case reports found that long-deceased cadavers can produce capnographic waveforms. The purpose of this study was to determine the predictive value of waveform capnography for endotracheal tube placement verification and detection of misplacement using a cadaveric experimental model.

Methods: We conducted a controlled experiment with two intubated cadavers. Tubes were placed within the trachea, esophagus, and hypopharynx utilizing video laryngoscopy. We recorded observations of capnographic waveforms and quantitative end-tidal carbon dioxide ($ETCO_2$) values during tracheal versus extratracheal (i.e., esophageal and hypopharyngeal) ventilations.

Results: 106 and 89 tracheal ventilations delivered to cadavers one and two, respectively ($n = 195$) all produced characteristic alveolar waveforms (positive) with $ETCO_2$ values ranging 2–113 mmHg. 42 esophageal ventilations (36 to cadaver one and 6 to cadaver two), and 6 hypopharyngeal ventilations (4 to cadaver one and 2 to cadaver two) all resulted in non-alveolar waveforms (negative) with $ETCO_2$ values of 0 mmHg. Esophageal and hypopharyngeal measurements were categorized as extratracheal ($n = 48$). A binary classification test showed no false negatives or false positives, indicating 100% sensitivity (NPV 1.0, 95%CI 0.98–1.00) and 100% specificity (PPV 1.0, 95%CI 0.93–1.00).

Conclusion: Though current guidelines question the reliability of waveform capnography for verifying endotracheal tube location during low-perfusion states such as cardiac arrest, our findings suggest that it is highly sensitive and specific.

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* Corresponding author. Fax.: +1 321 843 6220.
E-mail address: jamfort@gmail.com (J.F. Brown).

[1] Orlando Regional Medical Center, Orlando, FL, United States; University of Florida College of Medicine, Gainesville, FL, United States; Florida State University College of Medicine, Tallahassee, FL, United States; University of Central Florida College of Medicine, Orlando, FL, United States; Office of the Medical Director, Orange County EMS, Orange County, FL, United States.

[2] Orlando Regional Medical Center, Orlando, FL, United States; University of Florida College of Medicine, Gainesville, FL, United States; University of Central Florida College of Medicine, Orlando, FL, United States.

[3] Orlando Regional Medical Center, Orlando, FL, United States.

[4] Orlando Regional Medical Center, Orlando, FL, United States; Florida State University College of Medicine, Tallahassee, FL, United States; University of Central Florida College of Medicine, Orlando, FL, United States; Office of the Medical Director, Orange County EMS, Orange County, FL, United States.

[5] Orlando Regional Medical Center, Orlando, FL, United States; University of Florida College of Medicine, Gainesville, FL, United States; Florida State University College of Medicine, Tallahassee, FL, United States; University of Central Florida College of Medicine, Orlando, FL, United States.

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Introduction

Endotracheal intubation is a high-risk procedure commonly performed during medical and trauma resuscitations. The main cause of morbidity and mortality during intubation is unintentional extratracheal intubation. In-hospital misplacement rates of 3–18% have been reported,[1,2] and there is further evidence to suggest that this is even more problematic in prehospital airway interventions, with misplacement rates ranging from 6 to 25%.[3–7] In fact, reviews of the 2008 and 2012 National Emergency Medical Services Information System (NEMSIS) data showed unrecognized misplaced intubation rates of 23% and 15%, respectively.[8,9] Methods for confirming endotracheal tube (ETT) placement and detecting misplacement are the subject of ongoing clinical research, editorials, consensus panels, and audits.[10–12] Many institutions now regard end-tidal carbon dioxide ($ETCO_2$) detection as a gold standard safety measure for verifying tube placement.[13,14]

In 2010 the American Heart Association (AHA) International Consensus on Cardiopulmonary Resuscitation (CPR) and Emergency Cardiovascular Care (ECC) recommended routine use of waveform capnography for endotracheal verification.[3] This recommendation was continued in the 2015 guidelines.[15] However, the AHA and other guidelines, both before and after 2010, have cautioned against its reliability in low-perfusion states, such as cardiac arrest.[3,15–17]

Conflicting evidence has understandably led to disparate opinions and practices among providers of emergency airway care. Misconceptions regarding capnography, however, may be dangerous. Quality reviews and audits have demonstrated that misattribution of absent $ETCO_2$ waveform to cardiac arrest has resulted in unrecognized esophageal intubations. In 2011, for example, the Fourth National Audit Project of the Royal College of Anaesthetists (NAP4) reviewed three esophageal intubations (one which resulted in death) where lack of capnographic waveform was incorrectly attributed to cardiac arrest.[10] Furthermore, review of an observational registry of cardiac arrests found that return of spontaneous circulation was more likely after ETT position was verified by capnography.[18]

Recent observations have potentially uncovered a new medium for experimental investigation into the utility of capnography for verification of ETT placement. Reid et al. and Coats et al. remarkably demonstrated sustained life-like capnographic waveforms in intubated human cadavers with values up to 45 mmHg.[19,20] In light of these findings, we saw a unique opportunity to clarify the vexed topic of low-perfusion $ETCO_2$. We replicated and expanded the Reid and Coats studies to devise an experiment investigating the predictive value of capnography for determining tube position in the low-perfusion physiology of human cadavers. We believe the findings from this experiment can be extrapolated to the clinical scenario of acute cardiopulmonary arrest. We sought to evaluate characteristic capnographic waveforms and quantitative $ETCO_2$ values of positive-pressure ventilations delivered via tracheal and extratracheal (esophageal and hypopharyngeal) tubes.

Methods

Study design

A cadaveric experimental study was conducted on June 17, 2015 in a dedicated multipurpose room at Orlando Regional Medical Center, a regional tertiary care Level I trauma center in Central Florida. Ethics committee approval was granted before the study was conducted. The study was exempted by the institutional review board and deemed a non-human subjects investigation.

Table 1
Characteristics of human study cadavers.[a]

	Cadaver 1	Cadaver 2
Age (years)	103	56
Gender	Female	Female
Cause of death[b]	Respiratory failure	Brain Malignancy
Date of death (M/D/Y)	4/25/2015	4/28/2015
Embalmed[c]	No	No
Date frozen (M/D/Y)	4/27/2015 (2 days postmortem)	4/29/2015 (1 day postmortem)
Date thawed (M/D/Y)	6/10/2015(46 days postmortem)	6/10/2015 (43 days postmortem)
Total days frozen	44	42

The experiments were conducted on June 17, 2015; 7 days after both cadaveric specimens were thawed. Both cadaveric donors provided self-signed consent for all procedures performed.

[a] All information pertaining to both cadaveric specimens and their management was provided by The Medical Education & Research Institute (MERI, Memphis, TN).

[b] Cause of death refers to the cause documented by the MERI. No additional details regarding the circumstances of either cadaveric donor's death were available to the authors.

[c] Neither cadaver was exposed to any embalming chemicals.

Interventions

After endotracheal, esophageal, and hypopharyngeal intubations of two thawed cadavers, the authors delivered bag-valve ventilations while simultaneously measuring waveform and quantitative $ETCO_2$ values. The key exposure in this investigation was tracheal versus extratracheal (esophageal and hypopharyngeal) intubation.

Cadaver procurement and preparation

Two frozen human cadavers were procured through the Genesis Program of the Medical Education & Research Institute (MERI, Memphis, TN) for an intraosseous (IO) cannulation skills course. Representatives from EZ-IO (Teleflex Inc., Wayne, PA) generously consented to our use of the cadavers for airway manipulation. The skills course and our experiment were conducted simultaneously. Table 1 details the characteristics of both cadavers.

Experimental procedure

All procedures including intubation and ventilation were video recorded with a Sony HDR-CX190 (Sony Electronics Inc., San Diego, CA) and iPhone 6 (Apple Inc., Cupertino, CA). Each cadaver underwent endotracheal intubation with a 7.5 mm cuffed tube via video laryngoscopy using a GlideScope LoPro S4 blade (Verathon Inc., Bothell, WA). Each cadaver then underwent esophageal intubation such that both the tracheal and esophageal tubes were in place simultaneously (Supplementary Fig. 1). In both circumstances the cuffs were inflated with sufficient pressure to inflate the pilot balloon. The intubations were performed by a postgraduate year 3 (PGY-3) emergency medicine resident supervised by two board certified emergency medicine faculty. To verify proper positioning throughout the experiment, placement of both tubes was periodically reassessed by reinserting the GlideScope blade. The investigators were not blinded to the tube positions.

In each cadaver, approximately halfway through the experiment, the esophageal tube was removed and the tracheal tube was then retracted into a hypopharyngeal position. For the purposes of our study, a hypopharyngeal location was defined as supraglottic positioning of the tube bevel with the cuff inflated within the hypopharynx, and an unoccluded glottic opening (Supplementary Fig. 2). This was performed by the same PGY-3 resident under GlideScope visualization. The cuff was inflated to a pressure sufficient to inflate the pilot balloon.