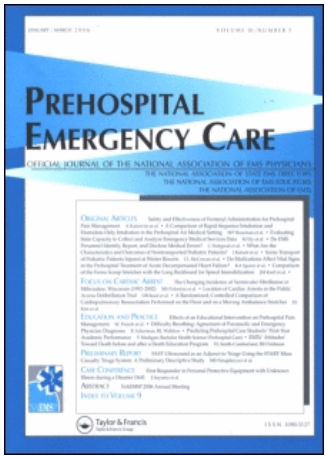

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Predictors of Intubation Success and Therapeutic Value of Paramedic Airway Management in a Large, Urban EMS System

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ORIGINAL ARTICLES

PREDICTORS OF INTUBATION SUCCESS AND THERAPEUTIC VALUE OF PARAMEDIC AIRWAY MANAGEMENT IN A LARGE, URBAN EMS SYSTEM

Daniel P. Davis, MD, Roger Fisher, EMT-P, Colleen Buono, MD, Criss Brainard, EMT-P, Susan Smith, RN, Ginger Ochs, RN, Jennifer C. Poste, James V. Dunford, MD

ABSTRACT

Background. Endotracheal intubation (ETI) is commonly used by paramedics for definitive airway management. The predictors of success and therapeutic value with regard to oxygenation are not well studied. **Objectives.** 1) To explore the relationship between intubation success and perfusion status, Glasgow Coma Scale (GCS) score, and end-tidal carbon dioxide ($EtCO_2$); 2) to describe the incidence of unrecognized esophageal intubations with use of continuous capnometry; and 3) to document the incremental benefit of invasive versus noninvasive airway management techniques in correcting hypoxemia. **Methods.** This was a prospective, observational study conducted in a large urban emergency medical services system. Paramedics completed a telephone debriefing interview with quality assurance personnel following delivery of all patients in whom invasive airway management had been attempted. Continuous capnometry was used for confirmation of tube position in all patients. Descriptive statistics were used to document airway management performance, including first-attempt ETI success, overall ETI success, and Combitube insertion (CTI) success. In addition, the incidence of unrecognized esophageal intubation was recorded. The relationship between intubation success and perfusion status, GCS score, and initial $EtCO_2$ value was explored using logistic regression. Finally, recorded SpO_2 values and the incidence of hypoxemia ($SpO_2 < 90\%$) at baseline, following noninvasive airway maneuvers, and after invasive airway management were compared for perfusing patients. **Results.** A total of 703 patients were enrolled over 12 months. First-attempt ETI success was 61%, and overall ETI success was 81%; invasive airway management (ETI or CTI) was unsuccessful in 11% of patients. A single unrecognized esophageal intubation was observed (0.1%). A clear relationship between airway management success and perfusion status, GCS score, and initial $EtCO_2$ value was observed. Only $EtCO_2$ demonstrated an independent association with ETI success after adjusting for the other variables. Significant improvements in mean SpO_2 and the incidence of hypoxemia over baseline were observed with both noninvasive and invasive airway management techniques in 168 perfusing patients. **Conclusions**. A relationship between intubation success and perfusion status, GCS score, and initial $EtCO_2$ value was observed. Capnometry was effective in eliminating unrecognized esophageal intubations. Both noninvasive and invasive airway management strategies were effective in increasing SpO_2 values and decreasing the incidence of hypoxemia, with additional benefit observed with invasive airway maneuvers in some patients. **Key words:** endotracheal intubation; emergency medical services; end-tidal carbon dioxide.

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INTRODUCTION

Endotracheal intubation (ETI) is commonly used by prehospital personnel to provide airway protection from aspiration with decreased levels of consciousness and to improve oxygenation.[1–6] While this skill is within the scope of practice of paramedics, data regarding the success of the procedure has come mainly from studies focusing on specific disease states such as cardiac arrest, traumatic brain injury (TBI), or following administration of neuromuscular blocking agents.[7–18] A notable exception is the analysis by Wang et al., which documented higher intubation rates among patients with a chief complaint of cardiac arrest and established perfusion status as an important covariate in airway management studies.[19] Recent in-hospital intubation studies have defined additional end points to improve discriminatory ability, including first-attempt success rate, number of ETI attempts, and success with

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rescue airway strategies.[20,21] These end points have not been explored with paramedic airway management.

Several recent analyses have documented an increase in mortality with prehospital intubation and ventilation in both cardiac arrest and TBI.[22–32] It is unclear whether this is due to preventable factors, such as desaturations following administration of neuromuscular blocking agents or hyperventilation following successful intubation, or whether the inherent detrimental effects of intubation and positive-pressure ventilation offset any potential benefits with regard to airway protection and oxygenation.[23,33,34] Thus, a risk-benefit ratio must be considered when determining whether to proceed with invasive airway management. However, previous studies documenting improved oxygenation following intubation have not considered the incremental benefit of invasive over noninvasive techniques.

We performed a prospective observational study of invasive airway management by our paramedics over a 12-month period. The main objective was to explore the relationship between intubation success and perfusion status, Glasgow Coma Scale (GCS) score, and initial end-tidal carbon dioxide ($EtCO_2$) value. In addition, the incidence of unrecognized esophageal intubations with use of capnometry was described and the additional benefit of invasive over noninvasive airway maneuvers with regard to oxygenation was explored.

METHODS

Design

This was a prospective, observational study conducted in a large, urban emergency medical services (EMS) system. Exemption from informed consent was granted by the UC San Diego Investigational Review Board.

EMS System

The city of San Diego has a population of 1.4 million, with EMS services provided by a single, fire-based agency that includes more than 400 paramedics. The initial response to the vast majority of critically ill patients includes a paramedic on a fire engine followed by at least one paramedic on the transport unit. Training, quality assurance, and medical direction are provided by San Diego Medical Services Enterprises. The current paramedic scope of practice for San Diego County includes ETI for patients with altered level of consciousness, severe dyspnea or hypoxia not responding to noninvasive airway management strategies, airway compromise, and cardiac or traumatic arrest. Contraindications include clenched jaw or presence of intact airway reflexes. Combitube insertion (CTI) is indicated as a rescue airway management strategy. Medication-assisted intubation is not routinely practiced by paramedics in San Diego County and neuromuscular blocking agents are carried only by air medical crews, who were not included in this study. Training in GCS scoring was instituted during the San Diego Paramedic RSI Trial, with appropriate accuracy demonstrated in a previous analysis.[35]

During the study period, confirmation of tube position was performed using mainstream digital capnometry (M Series; Zoll Medical Systems, Chelmsford, MA). An initial $EtCO_2$ value was recorded with bag-value-mask (BVM) ventilation immediately before ETI attempts; confirmation of proper tube position required that postintubation $EtCO_2$ values be the same or higher than observed with BVM ventilation. Removal of the tube was indicated with any suspicion of esophageal placement following ETI attempts or if tube position could not be confirmed following CTI. Tube placement was ultimately confirmed at the receiving facility. If an unrecognized esophageal intubation was suspected or confirmed by the emergency physician, an agency supervisor was immediately dispatched to interview hospital and prehospital personnel to determine the circumstances and significance of the event. The ultimate determination as to whether an esophageal intubation had occurred was made through the Prehospital Audit Committee, a county-wide organization that provides oversight and quality assurance to the San Diego EMS system.

Subjects

For a 12-month period, paramedics performed a mandatory telephone debriefing with San Diego Medical Services Enterprises quality assurance personnel for all patients undergoing attempts at either ETI or CTI. An attempt was defined by the insertion of a laryngoscope blade with the intent of achieving ETI or CTI. The debriefing was performed immediately on delivery of the patient to the emergency department or following field pronouncement and involved completion of a data collection tool as well as educational feedback for any identified quality assurance issues. The electronic medical record was queried regularly to assure capture of patients typically requiring intubation, including traumatic coma and those undergoing cardiopulmonary resuscitation. The following data were collected during the interviews and used in this analysis: chief complaint; vital signs and oxygen saturation (SpO_2) values before the administration of supplemental oxygen or performance of airway maneuvers, following noninvasive airway maneuvers, and after ETI or CTI; the use of a nasopharyngeal airway, oropharyngeal airway, or BVM ventilation; and the number and success of all ETI and CTI attempts. During the study, SpO_2 values were measured using pulse oximetry (M Series, Zoll Medical Systems).

Data Analysis

Paramedic airway management success and the incidence of unrecognized esophageal intubation with use of capnometry were presented descriptively. Airway management success was reflected by first-attempt ETI success rate, overall ETI success rate, and rate of successful CTI. The main objective of this analysis was to explore a potential relationship between intubation success and perfusion status, level of consciousness, and initial $EtCO_2$ value. We hypothesized that airway management success would increase with decreased perfusion, as reflected by lower systolic blood pressure (SBP) and $EtCO_2$ values, and with lower GCS scores.[36] Patients were stratified by perfusion status (nonperfusion, hypoperfusion, normoperfusion), GCS score (3, 4–8, 9+), and initial $EtCO_2$ value (0–15, 16–30, 31+). Nonperfusion was defined by a nonmeasurable SBP with a pulse rate of <40 beats/min, hypoperfusion was defined by an SBP 1–89 mm Hg or the absence of a measurable SBP but a heartrate of 40 beats/min or greater, and normoperfusion was defined by an SBP 90 mm Hg or greater.[37–41] Patients within each stratification were compared based on first-attempt ETI success, overall ETI success, and the "no invasive airway" rate (no ETI or CTI) using chi-square and chi-square test for trend. Logistic regression was used to determine the independent association between intubation success and perfusion status, GCS score, and $EtCO_2$ value, with patients stratified as described previously. Goodness of fit was assessed using Hosmer–Lemeshow testing.

The improvement in oxygenation with noninvasive and invasive airway management techniques was also explored. Mean SpO_2 values at baseline and following noninvasive and invasive airway maneuvers were compared using repeat-measures analysis of variance and Mann–Whitney testing. In addition, the incidence of hypoxemia ($SpO_2 < 90\%$) at baseline and with noninvasive and invasive airway management strategies was compared using chi-square test. Statistical calculations were performed using StatsDirect (StatsDirect Software Inc., Ashwell, United Kingdom).

RESULTS

A total of 703 patients were enrolled during the 12-month study period. Chief complaint, vital sign, and airway management success data are displayed in Table 1. During the study, a single unrecognized esophageal intubation was documented (0.1%). Review of the capnometry tracing revealed a sudden decrease in $EtCO_2$ to near-zero values that was not recognized by the treating paramedic. The incidence of first-attempt ETI, overall ETI, and CTI success as well as the incidence of "no invasive airway" are displayed in Table 2, with patients stratified by perfusion status, initial $EtCO_2$ value, and GCS score. The incidence of overall ETI success for all patients and after stratification based on perfusion status, initial $EtCO_2$ value, and GCS score are displayed in Figure 1. A progression for intubation success was observed with all three factors, with higher intubation success observed in nonperfusing patients and in those with lower $EtCO_2$ and GCS values. The results of the logistic regression analysis are displayed in Table 3. Model analysis suggested appropriate goodness of fit (Hosmer-Lemeshow $p = 0.305$). An expected interaction between the variables was observed. Of note, only an initial $EtCO_2$ value of 0–15 mm Hg was associated with intubation success after controlling for each of the other variables.

A total of 168 perfusing patients were included in the hypoxemia analysis. Mean and median values for initial, interim, and final SpO_2 and the incidence of

TABLE 1. Demographic and Clinical Data for All Patients (N = 703) Enrolled in the Study.

Variable	No. (%)
Chief complaint	
Cardiopulmonary resuscitation	512 (72.8)
Altered level of consciousness	37 (5.3)
Trauma	66 (9.4)
Respiratory distress	24 (3.4)
Other	24 (3.4)
Initial vital signs	
SBP measurable	158 (22.5)
Heart rate ≥40 beats/min	208 (29.6)
GCS score	
3	567 (80.7)
4–8	32 (4.6)
9+	44 (6.3)
Not documented	60 (8.5)
Airway management	
First attempt ETI	425 (60.5)
Second attempt ETI	118 (16.8)
Third attempt ETI	25 (3.6)
Fourth attempt ETI	1 (0.1)
Combitube insertion	55 (7.8)
No airway	79 (11.2)

TABLE 2. Data Regarding First-Attempt ETI Success, Any Attempt ETI Success, Combitube Insertion Success, and No Invasive Airway for All Patients (N = 703) in the Study

Patient Groups	First Attempt ETI	Any Attempt ETI	Combitube	No Airway
All patients (n = 703)	425 (61)	569 (81)	55 (8)	79 (11)
Hemodynamics				
Nonperfusion (n = 535)	349 (65)	457 (85)	45 (9)	33 (6)
Hypoperfusion (n = 70)	35 (50)	53 (76)	4 (6)	13 (19)
Normoperfusion (n = 98)	41 (42)	59 (60)	6 (6)	33 (34)
Initial GCS score				
3 (n = 567)	359 (63)	469 (83)	48 (9)	50 (9)
4–8 (n = 32)	10 (31)	17 (53)	1 (3)	14 (44)
9+ (n = 44)	21 (48)	30 (68)	4 (9)	10 (23)
Initial $EtCO_2$ value				
0–15 (n = 228)	147 (65)	205 (95)	15 (7)	8 (4)
16–30 (n = 154)	108 (70)	131 (85)	11 (7)	12 (8)
31+ (n = 86)	52 (61)	66 (77)	12 (14)	8 (9)

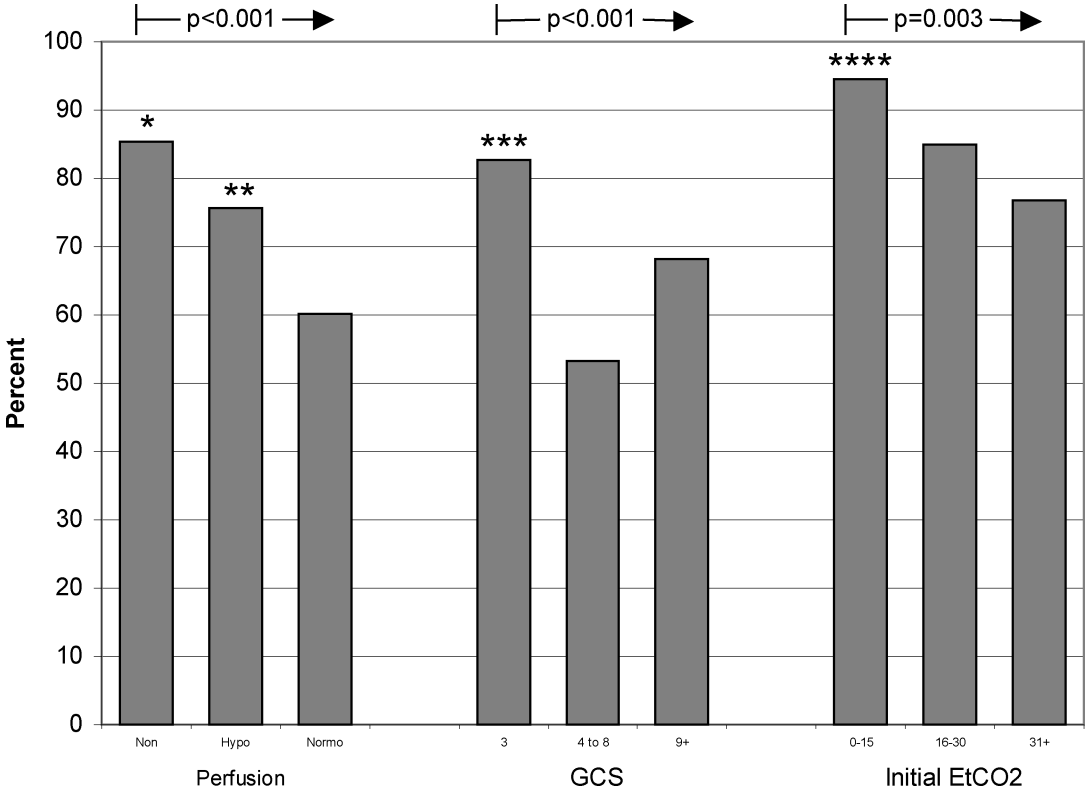

FIGURE 1. ETI success by various clinical variables. Chi-square test for trend p-values are shown at the top for GCS score and initial $EtCO_2$ value. *$p < 0.001$ vs. nonperfusing, p.05 vs. hypoperfusing; **$p < 0.05$ vs. normoperfusing; ***$p < 0.001$ vs. both 4–8 and 9+ groups; ****$p < 0.01$ versus 31+ groups.

hypoxemia ($SpO_2 < 90\%$) are displayed in Table 4. Significant improvements in mean and median SpO_2 values and the incidence of hypoxemia were observed with noninvasive airway maneuvers over baseline and with invasive airway maneuvers over both baseline and noninvasive airway maneuvers. Initial hypoxemia ($SpO_2 < 90\%$) was present in 58 of 79 patients (73%) in whom SpO_2 values were documented. Of these, normoxia was achieved in 21 of 58 patients (36%) with noninvasive airway management and in 34 of 58 patients (59%) with invasive airway management. Hypoxemia following noninvasive airway maneuvers was present in 57 of 112 patients (51%) in whom SpO_2 values were documented. Of these, normoxia was achieved in 18 of 57 patients (32%) after ETI or CTI.

TABLE 3. Logistic Regression Model to Predict the Likelihood of ETI Success, Adjusting for Hemodynamic Status, Initial GCS Score, and Initial $EtCO_2$ Value

Patient Groups	Odds Ratio (95% Confidence Interval)
Hemodynamics	
Nonperfusion	1.6 (0.9–2.7)
Hypoperfusion	1.1 (0.5–2.5)
Normoperfusion	1.1 (0.6–2.0)
Initial GCS score	
3	1.9 (1.0–3.4)
4–8	0.5 (0.2–1.2)
9+	1.9 (0.8–4.6)
Initial $EtCO_2$ value	
0–15	1.7* (1.2–2.6)
16–30	1.3 (0.8–1.9)
31+	0.8 (0.5–1.3)

*$p < 0.05$.

DISCUSSION

Here we document an association between intubation success and both perfusion status and level of

TABLE 4. Mean (95% Confidence Intervals) and Median (25th to 75th Percentile) SpO_2 Values at Baseline and Following Noninvasive and Invasive (ETI or CTI) Airway Management Strategies

	Baseline (n = 79)	After Noninvasive Airway Maneuvers (n = 112)	After Invasive Airway Management (n = 158)
Mean	69.4 (63.9–74.8)	82.5* (78.4–86.5)	86.0† (82.8–89.2)
Median	77 (56–90)	88.5* (71–98)	96‡ (80–99)
Incidence of hypoxemia (%)	73.4	50.9§	32.3‖

*$p < 0.001$ vs. baseline.
†$p < 0.001$ vs. baseline, $p < 0.01$ vs. noninvasive airway maneuvers.
‡$p < 0.001$ vs. baseline and noninvasive airway maneuvers.
§$p < 0.01$ vs. baseline.
‖$p < 0.01$ vs. baseline, $p < 0.05$ vs. noninvasive airway maneuvers.

consciousness. Interestingly, the initial $EtCO_2$ value was the only variable independently associated with intubation success after adjusting for each of the other variables. In addition, improvements in oxygenation were observed for both noninvasive and invasive airway management strategies. Finally, an extremely low incidence of undetected esophageal intubation (0.1%) was observed using a novel tube confirmation strategy focusing on the use of digital capnometry. This reflects the effectiveness of continuous quantitative capnometry to perform both the initial and ongoing confirmation of tube placement.[42,43] In addition, use of the preintubation $EtCO_2$ value to define a threshold to indicate tracheal placement is a unique approach that may help facilitate tube confirmation in arrest patients.

The ability of paramedics to intubate a patient without use of neuromuscular blocking agents is likely a reflection of neurologic integrity, which in turn is determined by cerebral perfusion or the presence of severe TBI. The decision to attempt intubation is also affected by these factors, further complicating this issue. In addition, clinical information gathered as part of the decision to attempt ETI, such as assessing for clenched jaw, difficulty with secretions, or gag reflexes, is not currently quantifiable.[6,18,19,35] These are likely related to, but still distinct from, more readily measurable factors such as perfusion state or level of consciousness. The relationship between $EtCO_2$ and intubation success is intriguing and likely reflects the large percentage of cardiac arrest victims and the prognostic value of $EtCO_2$ in this group.[44] The $EtCO_2$ value would not be expected to predict intubation success in patients with neurologic derangement but normal perfusion.[35]

Previous analyses of prehospital airway management have generally considered intubation as a covariate rather than the primary outcome variable.[24,26–32] Reported success rates for intubation have varied from near 100% for cardiac arrest victims to <50% for patients with severe TBI.[18,19] The majority of prehospital analyses that focus on intubation success rate as the main outcome measure involve the use of neuromuscular blocking agents.[7,8,10–15,17] While the advantage of such studies is the clear inclusion criteria, the physiology is clearly different with use of neuromuscular blockade. In addition, many of these studies involve air medical crews, which generally consist of flight nurses or specially trained paramedics.

The 81% ETI and 89% invasive airway management success rates observed here are consistent with previous reports if considering the variability in inclusion criteria.[8,16,18,19] The systematic prospective data collection process, the large number of patients, and the use of more discriminatory end points represent an improvement over existing data. Wang et al. reported intubation success rates for all patients with a documented ETI attempt using a large, statewide prehospital registry.[19] The overall ETI success rate of 86% was slightly higher than reported here, although this may reflect differences in the selection of patients for inclusion, because they used an electronic database rather than a telephone debriefing. In addition, their exploration of perfusion status as an influential factor in determining intubation success is consistent with the analysis performed here. They observed a 93% ETI success rate for cardiac arrest victims, while we observed 85% ETI success for nonperfusing patients and 95% success in patients with an initial $EtCO_2$ value of 0–15 mm Hg. They were not able to determine the number of intubation attempts or integrate GCS score or $EtCO_2$ value into the study but did use time to intubation as a surrogate for the ease of airway management. In addition, multiple prehospital agencies with various levels of training were included in their analysis.

The improvements in oxygenation with both noninvasive and invasive airway management techniques observed here included an increase in mean SpO_2 value and a decrease in the incidence of hypoxemia following noninvasive techniques and after invasive airway management. The observed benefit of invasive airway management techniques in correcting hypoxia at baseline and following noninvasive airway maneuvers is notable, because this provides support for the use of intubation in the treatment of critically ill and injured patients. It is not clear, however, that the improvements in oxygenation observed are either clinically significant or outweigh the potentially detrimental effects of invasive airway management.

The ability of intubation to improve oxygenation is certainly not a novel concept. Data from our own EMS system documented supratherapeutic arrival pO_2 values following paramedic rapid sequence intubation (RSI); however, the mean arrival pO_2 value was also above the normal range.[25,26,45] In addition, median SpO_2 values improved from 95% before RSI to 99% after RSI; baseline SpO_2 values were not recorded. Dorges et al. compared laryngeal mask airway, Combitube, cuffed oropharyngeal airway, and BVM with regard to oxygenation and ventilation in non-preoxygenated patients undergoing elective surgery.[46] All four strategies provided adequate ventilation, although significant air leakage was observed with BVM ventilation; however, desaturations during insertion were observed in all techniques except BVM. This same group observed lower pCO_2 values in patients undergoing small-tidal-volume BVM ventilation as compared with either larger-tidal-volume BVM ventilation or small-tidal-volume ventilation with a cuffed endotracheal tube.[47] They also observed better ventilation with a laryngeal mask airway and Combitube versus BVM in a bench model of resuscitation, with the Combitube displaying less gastric inflation but a slightly longer insertion time.[48]

These findings must be viewed in light of study limitations. Although data were collected prospectively in "real time" using a standardized data collection tool, the enrollment of patients was ultimately dependent on self-reporting by the paramedics. It is likely that many more patients were considered for intubation but deemed unable to be intubated due to a clenched jaw or intact gag reflex, with no subsequent intubation attempt made. Unlike the use of neuromuscular blocking agents, which more clearly defines the procedure, the assessment of the need for intubation involves a complex and subtle series of assessments that may or may not ultimately culminate in the performance of laryngoscopy. Similarly, some degree of reporting bias may have been present, especially because interviewers were also quality assurance officers. The use of $EtCO_2$ as a predictor of ETI success is unique but required that we use the initial $EtCO_2$ value, which may have been acquired using BVM ventilation. It is not clear whether $EtCO_2$ values measured following ETI are comparable to those obtained from BVM.

In addition, baseline, interim, and final oxygenation were each represented by a single recorded SpO_2 value. The inspection of continuous SpO_2 data would have several potential advantages, including the ability to validate reported data based on the strength of the signal and the progression from one SpO_2 value to the next. Similarly, it is difficult to ensure that low SpO_2 values were reflective of hypoxemia rather than hypoperfusion.[37,39–41,49–51] The elimination of values obtained in patients without a measurable SBP or with profound bradycardia should have addressed this issue to some extent. In addition, using the highest recorded SpO_2 value with each airway management technique should have helped to eliminate this source of error. However, it is possible that oxygenation would have continued to improve in successfully resuscitated patients, regardless of airway management strategy used.

We did not include outcomes as part of this analysis, and the inclusion of various chief complaint categories may reflect multiple different physiologies, because a postarrest patient with congestive heart failure may respond differently to various airway maneuvers than a patient with TBI. Furthermore, the impact of various degrees of hypoxemia on different disease entities is poorly understood.[52–54] Our previous work suggests that detrimental effects of hypoxemia are not observed until SpO_2 values decrease to $<70\%$ in patients with TBI.[53] However, the rapid decrease in SpO_2 value once the steep portion of the oxyhemoglobin dissociation curve is reached mandates that a higher SpO_2 threshold for concern be used. Finally, other indications for intubation, such as airway protection from aspiration, were not considered here but may be important in the decision to perform invasive airway management and in eventual outcomes.

CONCLUSIONS

An association between intubation success and perfusion status, GCS score, and initial $EtCO_2$ value was observed among paramedics in a large, urban EMS system. Overall intubation success was described using outcome measures of first-attempt ETI success, overall ETI success, and CTI success. In addition, a low incidence of unrecognized esophageal intubations was observed with use of continuous quantitative capnometry. Finally, improvements in oxygenation with both noninvasive and invasive airway management were documented, suggesting additional benefit to intubation over noninvasive airway maneuvers for some patients.

References

1. Aprahamian C, Darin JC, Thompson BM, Mateer JR, Tucker JF. Traumatic cardiac arrest: scope of paramedic services. Ann Emerg Med. 1985;14:583–6.
2. Aslanyan S, Weir CJ, Diener HC, Kaste M, Lees KR. Pneumonia and urinary tract infection after acute ischemic stroke: a tertiary analysis of the GAIN International trial. Eur J Neurol. 2004;11: 49–53.
3. Atherton GL, Johnson JC. Ability of paramedics to use the Combitube in prehospital cardiac arrest. Ann Emerg Med. 1993;22:1263–8.
4. Hatley T, Ma OJ, Weaver N, Strong D. Flight paramedic scope of practice: current level and breadth. J Emerg Med. 1998;16:731–5.
5. Smith JP, Bodai BI. The urban paramedic's scope of practice. JAMA. 1985;253:544–8.
6. Vadeboncoeur TF, Davis DP, Ochs M, Poste JC, Hoyt DB, Vilke GM. The predictive value of paramedic assessment of aspiration in patients undergoing prehospital rapid sequence intubation. J Emerg Med. 2004.
7. Falcone RE, Herron H, Dean B, Werman H. Emergency scene endotracheal intubation before and after the introduction of a rapid sequence induction protocol. Air Med J. 1996;15:163–7.
8. Garza AG, Gratton MC, Coontz D, Noble E, Ma OJ. Effect of paramedic experience on orotracheal intubation success rates. J Emerg Med. 2003;25:251–6.
9. Harrison TH, Thomas SH, Wedel SK. Success rates of pediatric intubation by a non-physician-staffed critical care transport service. Pediatr Emerg Care. 2004;20:101–7.
10. Hedges JR, Dronen SC, Feero S, Hawkins S, Syverud SA, Shultz B. Succinylcholine-assisted intubations in prehospital care. Ann Emerg Med. 1988;17:469–72.
11. Ochs M, Davis D, Hoyt D, Bailey D, Marshall L, Rosen P. Paramedic-performed rapid sequence intubation of patients with severe head injuries. Ann Emerg Med. 2002;40:159–67.
12. Pace SA, Fuller FP. Out-of-hospital succinylcholine-assisted endotracheal intubation by paramedics. Ann Emerg Med. 2000;35:568–72.
13. Sing RF, Rotondo MF, Zonies DH, Schwab CW, Kauder DR, Ross SE Brathwaite CC. Rapid sequence induction for intubation by an aeromedical transport team: a critical analysis. Am J Emerg Med. 1998;16:598–602.
14. Syverud SA, Borron SW, Storer DL, Hedges JR, Dronen SC, Braunstein LT, Hubbard BJ. Prehospital use of neuromuscular blocking agents in a helicopter ambulance program. Ann Emerg Med. 1988;17:236–42.
15. Vilke GM, Hoyt DB, Epperson M, Fortlage D, Hutton KC, Rosen P. Intubation techniques in the helicopter. J Emerg Med. 1994;12:217–24.

16. Vilke GM, Steen PJ, Smith AM, Chan TC. Out-of-hospital pediatric intubation by paramedics: the San Diego experience. J Emerg Med. 2002;22:71–4.
17. Wayne MA, Friedland E. Prehospital use of succinylcholine: a 20-year review. Prehosp Emerg Care. 1999;3:107–9.
18. Winchell RJ, Hoyt DB. Endotracheal intubation in the field improves survival in patients with severe head injury. Trauma Research and Education Foundation of San Diego. Arch Surg. 1997;132:592–7.
19. Wang HE, O'Connor RE, Schnyder ME, Barnes TA, and Megargel RE. Patient status and time to intubation in the assessment of prehospital intubation performance. Prehosp Emerg Care. 2001;5:10–18.
20. Sagarin MJ, Chiang V, Sakles JC, Barton ED, Wolfe RE, Vissers RJ Walls RM. Rapid sequence intubation for pediatric emergency airway management. Pediatr Emerg Care. 2002; 18:417–23.
21. Sivilotti MLA, Filbin MR, Murray HE, Slasor P, Walls RM. Does the sedative agent facilitate emergency rapid sequence intubation? Acad Emerg Med. 2003;10:612–20.
22. Aufderheide TP, Lurie KG. Death by hyperventilation: a common and life-threatening problem during cardiopulmonary resuscitation. Crit Care Med. 2004;32: S345–51.
23. Aufderheide TP, Sigurdsson G, Pirrallo RG, et al. Hyperventilation-induced hypotension during cardiopulmonary resuscitation. Circulation. 2004;109:1960–5.
24. Bochicchio GV, Ilahi O, Joshi M, Bochicchio K, Scalea TM. Endotracheal intubation in the field does not improve outcome in trauma patients who present without lethal traumatic brain injury. J Trauma. 2003;54:307–11.
25. Davis DP, Hoyt DB, Ochs M, Fortlage D, Holbrook T, Marshall LK, Rosen P. The effect of paramedic rapid sequence intubation on outcome in patients with severe traumatic brain injury. J Trauma. 2003;54:444–53.
26. Davis DP, Ochs M, Stern J, Holbrook T, Fortlage D, Rosen P, Hoyt DB. Factors associated with head-injury mortality following paramedic rapid sequence intubation: a final analysis of the San Diego Paramedic RSI Trial. J Trauma. 2005.
27. Davis DP, Peay J, Sise MJ, Vilke GM, Kennedy F, Eastman AB, Velky T, Hoyt DB. The impact of prehospital endotracheal intubation on outcome in moderate to severe traumatic brain injury. J Trauma., 2005;58:933–9.
28. Eckstein M, Chan L, Schneir A, Palmer R. Effect of prehospital advanced life support on outcomes of major trauma patients. J Trauma. 2000;48:643–8.
29. Gausche M, Lewis RJ, Stratton SJ, et al. Effect of out-of-hospital pediatric endotracheal intubation on survival and neurological outcome: a controlled clinical trial. JAMA. 2005;283: 783–90.
30. Murray JA, Demetriades D, Berne TV, et al. Prehospital intubation in patients with severe head injury. J Trauma. 2000;49:1065–70.
31. Wang HE, Peitzman AD, Cassidy LD, Adelson PD, Yealy DM. Out-of-hospital endotracheal intubation and outcome after traumatic brain injury. Ann Emerg Med. 2004;44: 439–50.
32. Wenzel V, Idris AH, Dorges V, et al. The respiratory system during resuscitation: a review of the history, risk of infection during assisted ventilation, respiratory mechanics, and ventilation strategies for patients with an unprotected airway. Resuscitation. 2001; 49:123–34.
33. Dunford JV, Davis DP, Ochs M, Doney M, Hoyt DB. Incidence of transient hypoxia and pulse rate reactivity during paramedic rapid sequence intubation. Ann Emerg Med. 2003; 42:721–28.
34. Pepe P, Raedler C, Lurie KG, Wigginton JG. Emergency ventilatory management in hemorrhagic states: elemental or detrimental? J Trauma. 2003;54:1048–55.
35. Davis DP, Vadeboncoeur TF, Ochs M, Poste JC, Vilke GM, Hoyt DB. The association between field Glasgow Coma Scale score and outcome in patients undergoing paramedic rapid sequence intubation. J Emerg Med, 2005;29:391–7.
36. Sehra R, Underwood K, Checchia P. End tidal CO2 is a quantitative measure of cardiac arrest. PACE. 2003;26:515–7.
37. Chawla R, Kumarvel V, Girdhar KK, Sethi AK, Indrayan A, Bhattacharya A. Can pulse oximetry be used to measure systolic blood pressure? Anesth Analg. 1992;74:196–200.
38. Delete. International consensus on science. Guidelines 2000 for cardiopulmonary resuscitation and emergency cardiovascular care. Resuscitation. 2005;46:1–447.
39. Langbaum M, Eyal FG. A practical and reliable method of measuring blood pressure in the neonate by pulse oximetry. J Pediatr. 1994;125:591–5.
40. Lawson D, Norley I, Korbon G, Loeb R, Ellis J. Blood flow limits and pulse oximeter signal detection. Anesthesiology. 1987;67:599–603.
41. Mateer JR, Olson DW, Stueven HA, Aufderheide TP. Continuous pulse oximetry during emergency endotracheal intubation. Ann Emerg Med. 1993;22:675–9.
42. Katz SH, Falk JL. Misplaced endotracheal tubes by paramedics in an urban emergency medical services system. Ann Emerg Med. 2001;37:32–7.
43. Silvestri S, Ralls GA, Krause B, et al. The effectiveness of out-of-hospital use of continuous end-tidal carbon dioxide monitoring on the rate of unrecognized misplaced intubation within a regional emergency medical services system. Ann Emerg Med. 2005;45:497–503.
44. Levine RL, Wayne MA, Miller CC. End-tidal carbon dioxide and outcome of out-of-hospital cardiac arrest. Engl J Med. 1997;337:301–6.
45. Ochs M, Vilke GM, Chan TC, Moats T, Buchanan J. Successful prehospital airway management by EMT-Ds using the combitube. Prehosp Emerg Care. 2000;4:333–7.
46. Dorges V, Wenzel V, Knacke P, Gerlach K. Comparison of different airway management strategies to ventilate apneic, nonpreoxygenated patients. Crit Care Med. 2003;31:800–4.
47. Dorges V, Hartmut O, Hagelberg S, Wenzel V, Idris AH, Schmucker P. Smaller tidal volumes with room-air are not sufficient to ensure adequate oxygenation during bag-value-mask ventilation. Resuscitation. 2000;44:37–41.
48. Doerges V, Sauer C, Ocker H, et al. Airway management during cardiopulmonary resuscitation—a comparative study of bag-value-mask, laryngeal mask airway and combitube in a bench model. Resuscitation. 1995; 41:63–9.
49. Barker SJ, Hyatt J, Shah NK, Kao YJ. The effect of sensor malpositioning on sensor accuracy during hypoxemia. Anesthesiology. 1993;79:248–54.
50. Jay GD, Hughes L, Renzi FP. Pulse oximetry is accurate in acute anemia from hemorrhage. Ann Emerg Med. 1994;24:.
51. Severinghaus JW, Koh SO. Effect of anemia on pulse oximeter accuracy at low saturation. J Clin Monitoring. 1990;6:85–8.
52. Barton CW, Hemphill JC, Morabito D, Manley G. A novel method of evaluating the impact of secondary brain insults on functional outcomes in traumatic brain-injured patients. Acad Emerg Med. 2005;12:1–6.
53. Davis DP, Dunford JV, Hoyt DB, Ochs M, Holbrook T, Fortlage D. The impact of hypoxia and hyperventilation on outcome following paramedic rapid sequence intubation of patients with severe traumatic brain injury. J Trauma. 2004.
54. Manley G, Knudson MM, Morabito D, Damron S, Erickson V, Pitts L. Hypotension, hypoxia, and head injury: frequency, duration, and consequences. Arch Surg. 2001;136:1118–23.