ORIGINAL CONTRIBUTIONS

AIRWAY MANAGEMENT SUCCESS AND HYPOXEMIA RATES IN AIR AND GROUND CRITICAL CARE TRANSPORT: A PROSPECTIVE MULTICENTER STUDY

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ABSTRACT

Objective. To assess critical care transport (CCT) crews' endotracheal intubation (ETI) attempts, success rates, and peri-ETI oxygenation. **Methods.** Participants were adult and pediatric patients undergoing attempted advanced airway management during the period from July 2007 to December 2008 by crews from 11 CCT programs varying in geography, crew configuration, and casemix; all crews had access to neuromuscular-blocking agents. Data collected included airway management variables defined per national consensus criteria. Descriptive analysis focused on ETI success rates (reported with exact binomial 95% confidence intervals [CIs]) and occurrence of new hypoxemia (oxygen saturation [SpO_2] dropping below 90% during or after ETI); to assess categorical variables, Fisher's exact test, Pearson χ^2, and logistic regression were employed to explore associations between predictor variables and ETI failure or new hypoxemia. For all tests, $p < 0.05$ defined significance. **Results.** There were 603 total attempts at airway management, with successful oral or nasal ETI in 582 cases, or 96.5% (95% CI 94.7–97.8%). In 182 cases (30.2%, 95% CI 26.5–34.0%), there were failed ETI attempts prior to CCT crew arrival; CCT crew ETI success on these patients (96.2%, 95% CI 92.2–98.4%) was just as high as in the patients in whom there was no pre-CCT ETI attempt ($p = 0.81$). New hypoxemia occurred in only six cases (1.6% of the 365 cases with ongoing SpO_2 monitoring; 95% CI 0.6–3.5%); the only predictor of new hypoxemia was pre-ETI hypotension ($p < 0.001$). A requirement for multiple ETI attempts by CCT crews was not associated with new hypoxemia (Fisher's exact $p = 0.13$). **Conclusions.** CCT crews' ETI success rates were very high, and even when ETI required multiple attempts, airway management was rarely associated with SpO_2 derangement. CCT crews' ETI success rates were equally high in the subset of patients in whom ground emergency medical services (EMS) ETI failed prior to arrival of transport crews. **Key words:** airway management; critical care transport; intubation; air medical; helicopter

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INTRODUCTION

One of the most controversial components of prehospital care is performance of endotracheal intubation (ETI). Reports have suggested that prehospital ETI may worsen outcomes, and commentators have emphasized the need for emergency medical services (EMS) systems to closely track rates of ETI success and complications.[1–9]

The success or failure of endotracheal tube (ETT) placement is only a part of the ETI safety picture. At least as important as getting the ETT in position is the avoidance of peri–airway management physiologic derangement (e.g., hypotension, hypoxemia, hypercarbia).[10–12]

Authors of recent ground EMS ETI studies continue to raise concerns about skills dilution, training challenges, and success and complication rates.[13,14] These issues are just as important for critical care transport (CCT) crews. The growing size of some programs' CCT crews has been anecdotally noted to pose problems of both dilution of ETI skills and reduced access to real-patient ETIs in training settings such as the operating room. These changes in CCT crews' ETI training and clinical opportunities have the potential to result in lower ETI success rates than those reported in older studies.[15,16]

This study's rationale was the perceived need, by investigators at a number of CCT programs, to prospectively assess ETIs performed in the transport setting. Previous individual CCT programs' high ETI success rates are well documented. The overarching goal for this collaborative multicenter study was to assess ETI performance and peri-ETI physiology in a large number of patients, over a time period (one year) short enough that there was little evolution of the standards of care and practice. The primary endpoints of this study were rates of successful ETI and new peri-ETI hypoxemia as reported by CCT crews trained to monitor and report lowest peri-ETI oxygen saturation (SpO_2). Secondary endpoints included factors (such as multiple ETI attempts) that may be associated with ETI failure or new hypoxemia. An additional endpoint, prompted by the spread of ground EMS ETI, was CCT crews' ETI success rates in patients in whom pre–CCT arrival ETI attempts had failed.

METHODS

Design and Interventions

This study was a prospective, consecutive-case analysis. Study variables and endpoints were defined by the investigators in Critical Care Transport Collaborative Outcomes Research Effort (CCT CORE) planning sessions. All variables, including those related to specific endpoints (e.g., SpO_2 nadir), were prospectively defined and crews were educated in the requirement for their documentation.

National Association of EMS Physicians (NAEMSP) airway criteria[7] were used to define the data to be used in the study. Next, a secure Web-based data-entry (Structured Query Language [SQL]-based) mechanism was set up on the Website of the study group (www.cctcore.org). This structured data form allowed for data entry from any computer (at participating program sites) with Internet connectivity. For approximately 10% of the transport records, which were also sent to the study coordinator center, rechecks of the hard-copy flight record vs. database-entered data confirmed the accuracy of the data entry. Review of these records by the principal investigator and a research assistant (MLS) revealed no significant discrepancies between chart data and data that had been entered into the database via the Web interface.

The method of uniform reporting was for each participating CCT program to complete the relevant information on its own ETI charts, in the time period closely following the transport of the patient. The study electronic case report forms were discussed before the institution of the study, with in-person training sessions at national prehospital care meetings. All programs used the same electronic case report forms to enter data, and all of the Web-based data-entry pages included definitions of variables being entered. The study included no active clinical intervention, and there was no randomization.

Setting and Population

The participating study CCT programs, with approximate annual transport volume, were as follows: Boston Medflight (3,600), Christiana Care LifeNet (500), Flight for Life Colorado (2,700), LifeFlight of Maine (1,400), LifeNet of New York (2,000), MedFlight of Ohio (4,400), Midwest Medflight (400), Ornge Transport Medicine (19,000), Sunstar CCT (1,300), University of Michigan Survival Flight (1,200), and STATAir (1,000). All of Sunstar CCT's transports were interfacility (ground) transports, with the remainder of the programs providing mostly air medical transport (see Figure 1 for relevant information on the airway management setting). STATAir's scene mission percentage was 60%. For the other programs, the proportion of scene runs ranged between 10% and 40%.

The study programs' crews are primarily registered nurses (RNs) and emergency medical technicians–paramedic (EMT-Ps); these crew types were responsible for all but eight of this study's 603 CCT airways managed. Some of the academic hospital-based programs do occasionally fly with resident or attending physicians. Additionally, most of the study programs transport neonates with special neonatal crews (airway management by specialized neonatal crews was not included in this data set).

At all participating CCT programs, the overseeing institutional review board (IRB) authority (or its Canadian equivalent) reviewed and approved the project. Written informed consent was waived. Additionally,

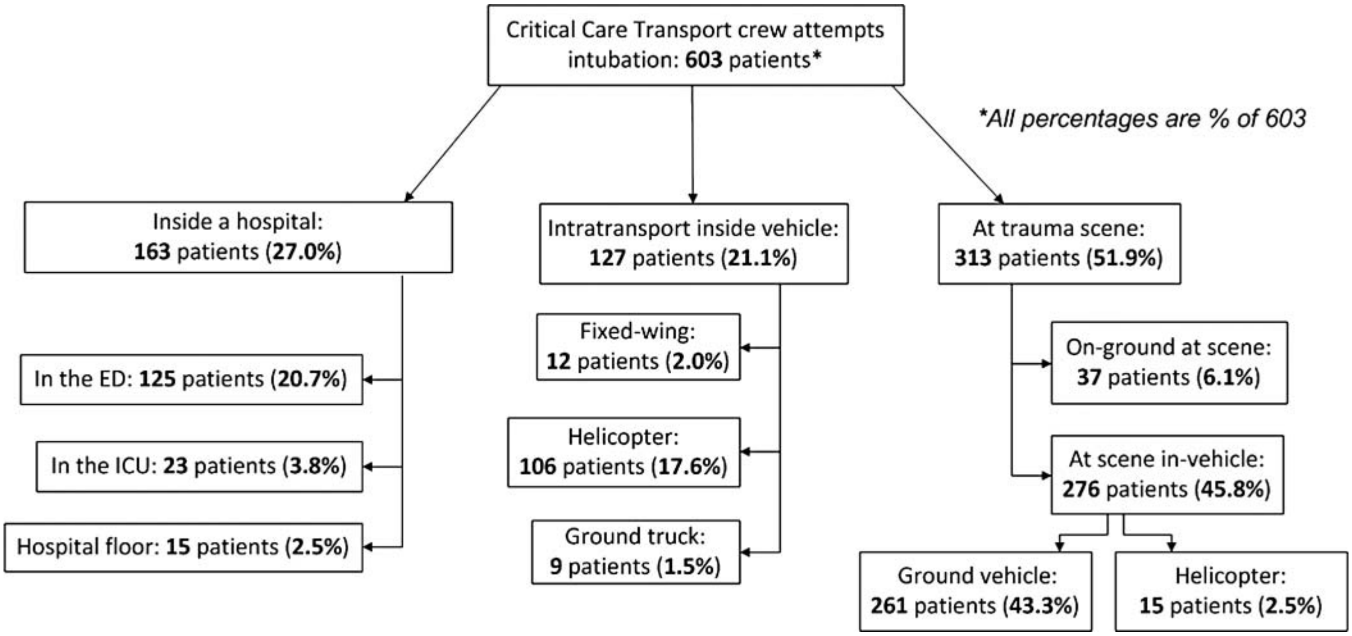

FIGURE 1. The airway management settings. ED = emergency department; ICU = intensive care unit.

the IRB at Harvard Medical School/Massachusetts General Hospital reviewed and approved the protocol, policies, and procedures for establishment and maintenance of the study database.

Measurements

Data variables collected in the CCT CORE Airway Study are outlined in Table 1. As previously noted, the definitions for these variables were designed to match the definitions in the NAEMSP position paper.[7] For "intubation attempt," for example, an oral attempt was defined as having been made if the laryngoscope was inserted into the mouth; a nasal ETI attempt was defined as having occurred if the tip of the nasal ETT was placed into the naris.

With respect to the physiologic variables, participating crews were educated in the SpO_2 nadir concept before the study period. Critical care transport crews, who already are trained to be vigilant about SpO_2 on a continuous basis during airway management, were instructed to document the SpO_2 nadir on the medical record as the record was completed. For the other physiologic variables, the true "nadir" was not recorded, but rather the study data instrument called for the lowest documented heart rate (HR) and blood pressure in the peri-ETI period.

Not all of the study variables were collected by all participating programs. Not all of the variables collected were used in the analysis for this report. All of the variables that constituted the focus of this report, and which are reported in Table 1, were collected by all programs.

Analytical Methods

The study's most important endpoints, such as ETT success rates, were analyzed with descriptive analysis including binomial exact confidence intervals (CIs). Further categorical analysis was executed using Pearson chi-square, Fisher's exact test, and logistic regression modeling for dichotomous endpoints such as "requirement for multiple ETI attempts." Logistic regression models were generated using the approach of Hosmer and Lemeshow,[17] with results reported as odds ratios (ORs) with 95% CIs. Because of the large potential number of analytic tables that could be generated (and used for hypothesis testing), and because some programs did not collect data on some of the (non–Table 1) study variables, not all variables were tested against all endpoints.

Continuous data analysis included assessment of means with standard deviations (SDs). For data determined to be nonnormally distributed (using Shapiro-Wilk testing), medians and interquartile ranges (IQRs) are reported. The medians' 95% CIs were calculated using the bootstrap method as described by Haukoos and Lewis.[18] Statistical significance was defined at an alpha level of 0.05.

RESULTS

Patients Comprising the Study Set

During the study period, there were 603 patients in whom CCT crews made at least one advanced airway management attempt. Each of the 11 participating programs contributed at least 20 patients to the study. Some programs entered relatively fewer patients

TABLE 1. Selected Variables (with Definitions) Collected in the Critical Care Transport Collaborative Outcomes Research Effort (CCT CORE) Airway Study

General descriptors
AgeYears—Patient age in years; decimals should be used for those younger than 1 year
WtKg—Weight in kg
AM Att Nmb—AM attempt number by the CCT crew
Tport time—Total time the crew spent with the patient
PreCCT AM By—Who performed AM prior to CCT team arrival
AM Setting—AM location (prehospital, referring hospital, in vehicle)
Tport Vehicle—Transport vehicle (FW, ground, helicopter)
AM indications
Indication Apnea Agonal—Indication(s) for AM included apnea or agonal respirations
Indication AirwayReflex—Airway reflex compromised and/or GCS < 9
Indication VentEffort—Ventilatory effort compromised
Indication AirwayInjry—Airway illness or injury
Indication PotentialComp—Potential for airway/ventilatory compromise
Indication RefractHypoxia—Patient with persistent hypoxemia
Pre-AM physiology and monitors in place
Arrest at AM—Patient in cardiac arrest at the time of the AM attempt
PreAM HR—HR just prior to the AM attempt
PreAM SBP—Systolic blood pressure just prior to the AM attempt
PreAM RR—Respiratory rate just prior to the AM attempt
PreAM SpO2—Pulse oximetry reading just prior to the AM attempt
PeriAM EKG—Code as 1 if there was ECG monitoring during AM
PeriAM SpO2—Code as 1 if pulse oximetry was used during AM
PeriAM EtCO2—Code 1 if $ETCO_2$ was monitored during AM
Airway manager credentials
AMgr1 Credentials—Level (EMT level, RN, RT, resident/attending physician) of airway manager 1
AMgr2 Credentials—Credentials of the second AM participant
AMgr3 Credentials—Credentials of the third individual performing an AM attempt
AM attempt: airway type, adjunctive placement maneuvers, and result of individual AM attempt
OETI Attmpted—Was there insertion of a laryngoscope blade as part of the ETI attempt?
NETI Attmpted—For nasal ETI, was there insertion of the ETT tip into the naris?
BVMcETI Attmpt—Did the patient undergo manual ventilation as part of the ETI attempt?
PeriAM Bougie— Bougie or ETT introducer was used to assist AM/ETI
OtherAdjunct—Was there another adjunct used peri-AM?
LryngScope—Laryngoscope type (Mac, Miller, Bullard, etc.)
ELM—Bimanual laryngoscopy/external laryngeal manipulation
Result AM—Was the result of this AM placement of an ETT in the trachea?
Ventilation—Result of this AM attempt: Was satisfactory ventilation achieved?
ETT placement confirmation
AM Result ETT Placement—Did the AM attempt result in placement of an ETT? (coded as 1 regardless of position)
ETT Location Tracheal—ETT intratracheal?
ETT Location Esophag—Esophageal tube placement (including if immediately recognized and removed)
ETT Location Indeterm—Uncertain tube placement (with tube immediately removed)
UnrecogEsophTube—Esophageal tube recognized after tube secured in place
Peri-AM medications
PreETI Sedation—Any sedation used for ETI
Diazepam—Diazepam dose in mg/kg
Midazolam—Midazolam dose in mg/kg
Etomidate—Etomidate dose in mg/kg
Morphine—Morphine dose in mg/kg
Fentanyl—Fentanyl dose in μg/kg
PreETI NMB—Any neuromuscular blockade
Peri-AM physiology and complications
SpO2 Nadir—Lowest oxygen saturation occurring during AM
PostAM HR—Post-AM heart rate
PostAM SBP—Post-AM systolic blood pressure
PostAM SpO2—Post-AM oxygen saturation
PostAM ETCO2—Post-AM $ETCO_2$ (number)

AM = airway management; CCT = critical care transport; ECG = electrocardiogram; EMT = emergency medical technician; ETCO2 = end-tidal carbon dioxide; ETI = endotracheal intubation; ETT = endotracheal tube; FW = fixed-wing; GCS = Glasgow Coma Scale score; HR = heart rate; RN = registered nurse; RT = respiratory therapist.

because they joined the study's prospective data entry after the initial study period had commenced.

The patients were mostly male (415, 68.8%), with median age of 39 years (range of neonate to 99 years, IQR 20–62 years). The median Glasgow Coma Scale score (GCS) was 7 (IQR 3–12). Patients had a breadth of documented indications for airway management (including GCS < 9 in 386 cases). ETI setting information is provided in Figure 1.

In 421 cases (69.8%), the diagnostic category was trauma; 392 (65.0%) of the 603 patients were scene transports. Other commonly encountered diagnostic categories in the study group were neurologic (68, 11.3%) and cardiac (54, 9.0%).

Medications administered to facilitate ETI included benzodiazepines (125, 20.7%), etomidate (474, 78.6%), and fentanyl (169, 28.0%). Neuromuscular blockade was used to facilitate ETI in 428 patients (71.0%).

The mean transport time was 53.4 minutes (SD 36.1 minutes), with a median of 43 minutes (IQR 31–66 minutes). Receiving units were usually emergency departments (EDs) (526, 87.2%), although some patients were delivered to the intensive care unit (ICU) (68, 11.3%) or operating suite (9, 1.5%).

Airway Management Results—Airway Placement

Endotracheal intubation was successful in 582 patients (96.5% of 603, 95% CI 94.7-97.8%). Table 2 and Figure 2 provide information about the airway management approach and ETI success.

Videolaryngoscopy was utilized in 12 patients (2.0%). In 25 patients (4.2%), a bougie was used to facilitate ETI.

Of the 603 overall cases, there were multiple ETI attempts by the CCT crew in 135 patients (22.4%, 95% CI 19.1–25.9%). This multiple-attempts number does not include any ETI attempts made by non–CCT crew practitioners (e.g., on-scene ground EMT-Ps, in-hospital physicians). Of the overall group of 603, there were non–CCT crew ETI failures in 182 (30.2%). In those 182 cases, pre-CCT ETI operators were usually scene ground EMT-Ps (129, 70.9% of 182) or hospital physicians (45, 24.7% of 182). The other eight cases of failed ETI prior to CCT arrival were evenly divided between hospital-based respiratory therapists and on-scene (volunteer/Good Samaritan) physicians.

There were zero unrecognized esophageal intubations (0%, one-sided 97.5% CI ranging up to 0.61%).

Success of ETI placement was not associated with age analyzed as a continuous variable ($p = 0.60$), or as divided into a priori–defined categories (0 to 1, >1 to 3, 4 to 17, and 18+ years; $p = 0.17$). There were no associations between ETI success and gender ($p = 0.79$), weight exceeding 100 kg ($p = 0.29$), scene vs. interfacility mission type ($p = 0.82$), or diagnostic group ($p = 0.41$). The endpoint of "multiple ETI attempts" was also unassociated with age assessed continuously ($p = 0.20$) or categorically ($p = 0.22$), gender ($p = 0.52$), weight exceeding 100 kg ($p = 0.14$), or scene vs. interfacility mission type ($p = 0.54$). The requirement for multiple attempts was significantly lower in the cardiac and general medical/surgical patients, as compared with those in the other diagnostic groups (neonatal, neurologic, and trauma; $p = 0.015$).

There was no association between pre–CCT crew ETI failure and CCT crew ETI failure ($p = 0.81$). Although analysis was limited by low cell counts, the high CCT crew ETI success rates were similar among patients

TABLE 2. Detailed Results of Airway Management and Intubation

Airway Placement Outcome	No. Patients	% of 603 (95% CI)
Oral ETT placed	566	100
Oral ETT on 1st attempt	445	73.8 (70.1–77.3)
Oral ETT on 2nd attempt	90	14.9 (12.2–18.0)
Oral ETT on 3rd attempt	18	3.0 (1.8–4.7)
Oral ETT on 4th attempt	8	1.3 (0.6–2.6)
Oral ETT on 5th attempt	4	0.66 (0.2–1.7)
Oral ETT on 7th attempt	1	0.17 (0.004–0.9)
Nasal ETT placed	16	2.7 (1.5–4.3)
Nasal ETT on 1st attempt	13	2.2 (1.1–3.7)
Nasal ETT on 2nd attempt	2	0.33 (0.04–1.2)
Nasal ETT on 3rd attempt	1	0.17 (0.004–0.9)
Non-ETT airways (all placed successfully on 1 attempt)	16	2.7 (1.5–4.3)
LMA placed as initial airway	5	8.3 (0.3–1.9)
LMA placed after 1 ETI attempt	2	0.33 (0.04–1.2)
LMA placed after 2 ETI attempts	4	0.66 (0.2–1.7)
LMA placed after 3 ETI attempts	1	0.17 (0.004–0.9)
Combitube placed as initial airway	1	0.17 (0.004–0.9)
Combitube placed after 1 ETI attempt	3	0.50 (0.1–1.4)
Surgical airway	3	0.50 (0.1–1.4)
Cricothyrotomy initial airway on 1 attempt	2	0.33 (0.04–1.2)
Cricothyrotomy after 1 ETI attempt	1	0.17 (0.004–0.9)
Bag–valve–mask after 1 ETI attempt	2	0.33 (0.04–1.2)

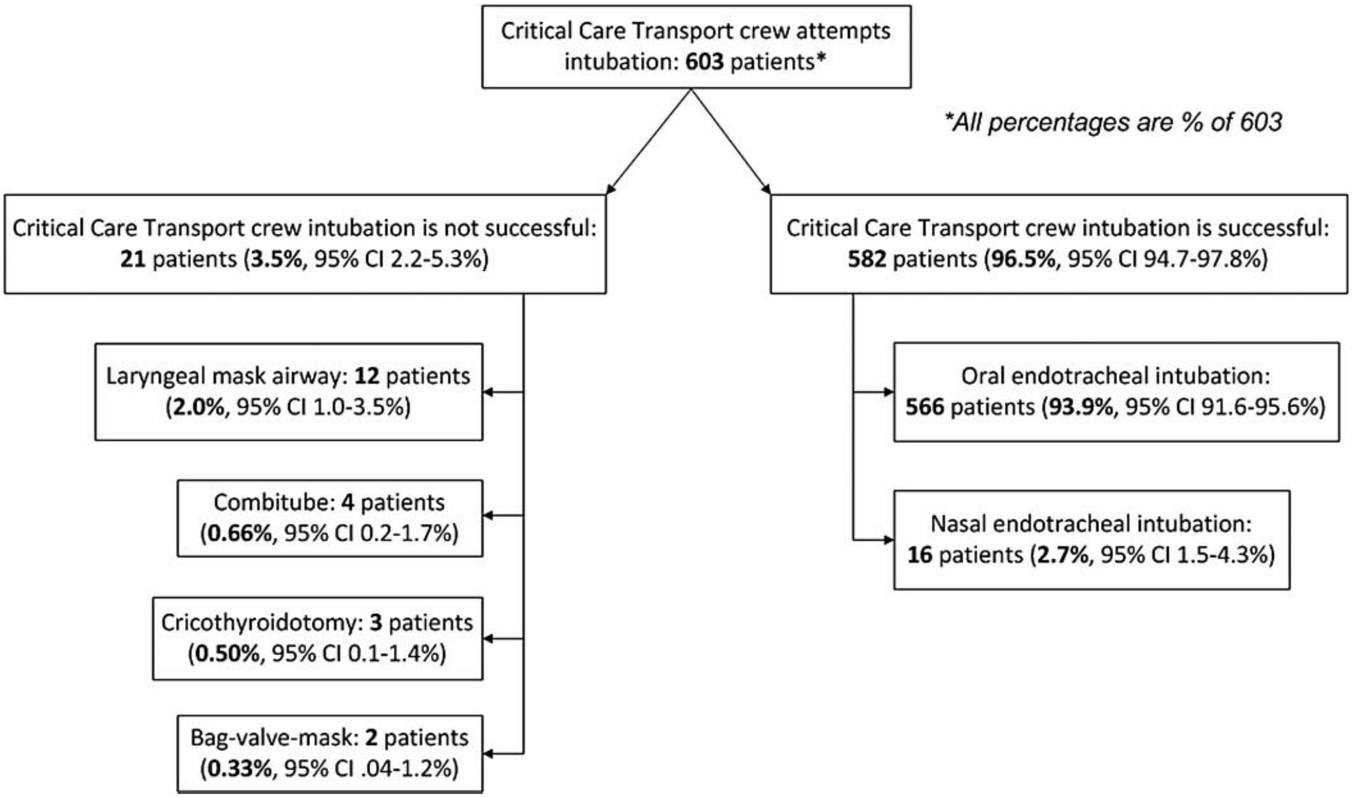

FIGURE 2. The overall airway management results. CI = confidence interval.

with pre-CCT ETI failures by the various types of operators (physicians, respiratory therapists, and scene EMT-Ps; $p < 0.001$). The failure of ETI attempts prior to CCT attempts was associated with the requirement for multiple ETI attempts by CCT crews ($p = 0.02$). As was the case for ETI success, the requirement for multiple CCT ETI attempts did not differ significantly depending on the credentials of the pre-CCT operator ($p = 0.76$).

Success rates for CCT crew ETI attempts while in hospital (97.6%), on scene (96.2%), and in transport (96.0%) were similar ($p = 0.77$). However, there was a greater need ($p < 0.001$) for multiple attempts at ETI when CCT crews performed the procedure in transport (37.3%) as compared with rate of requirement for multiple ETI attempts while in hospital (16.6%) or on scene (19.4%). Logistic regression identified a three-fold increase in the odds of requiring multiple attempts for intratransport ETI as compared with in-hospital ETI (OR 3.0, 95 CI 1.7–5.2, $p < 0.001$).

Airway Management Results—Peri-intubation Physiology

There was new bradycardia (HR < 60 beats/min) in 13 cases (2.3% of 564 cases with HR data, 95% CI 1.2–3.9%), although in five of the 13 cases the pre-ETI HR was in the low 60s (beats/min). There was no association between the development of new bradycardia and diagnostic group ($p = 0.43$), airway management setting ($p = 0.32$), or use of succinylcholine ($p = 0.07$). Logistic regression confirmed the higher risk of new bradycardia in patients requiring multiple ETI attempts (OR 3.5, 95% CI 1.1–10.5, $p = 0.03$).

Pre-ETI systolic blood pressure (SBP) was recorded in 561 patients, with 82 patients (14.6%) having SBP < 90 mmHg just prior to CCT ETI attempts. Development of new hypotension occurred in 23 cases (4.8% of the 479 patients with pre-ETI normotension, 95% CI 3.1–7.1%). The development of new hypotension was not associated with the requirement for multiple ETI attempts ($p = 0.31$), diagnostic group ($p = 0.43$), or airway management setting (p of 0.72).

Peri-ETI SpO_2 was recorded for 494 patients. In 92 cases (18.6%), hypoxemia was present ($SpO_2 < 90\%$) prior to CCT ETI attempts. The median pre-ETI SpO_2 was 98% (IQR 93–100%). The median post-ETI SpO_2 was 100% (IQR 98–100%). The peri-ETI SpO_2 nadir was documented in 411 cases. The median SpO_2 nadir was 98% (IQR 9–100%). For patients whose pre-ETI SpO_2 exceeded 90%, the peri-ETI SpO_2 nadir was below 90% in six cases (1.6%, 95% CI 0.6–3.5%). Of the six cases, half involved trauma scene patients and there were three in-hospital intubations (one cardiac and two neurologic). One of the six cases involved a patient who was in cardiac arrest before and during CCT airway management (with pre-ETI SpO_2 maintained by bag–valve–mask ventilation). Three of the patients had an oral ETT placed on the first attempt, and the other three patients were successfully orally intubated on the second attempt. While low numbers rendered analyses imprecise, there appeared to be no association between new hypoxemia and the requirement for multiple ETI attempts ($p = 0.08$). Small numbers prevented meaningful regression analysis.

In the 64 cases in which the pre-ETI SpO_2 was below 90%, CCT crew airway management resulted in increase in SpO_2 to above 90% in 48 cases (75%, 95% CI 62.6–85.0%). The CCT providers were more likely ($p < 0.001$) to improve oxygenation in hypoxic patients (75.0% chance) than they were to cause hypoxia in those patients who were already oxygenating well (1.6% chance, 95% CI 0.6–3.6%).

Discussion

The subject of ETI remains an area of keen interest in prehospital care. There is ongoing debate as to the circumstances under which advanced airway management should be performed in the field. Recent experts in ground EMS care have reported large-scale results of ETI in their regions, and highlighted the need for ongoing monitoring of EMS providers' practices of ETI.[13]

The current study was designed as a multicenter trial, with the aim of attaining relatively large study numbers, in a relatively short time period. The multicenter-trials network approach for acute care clinical research is a proven entity, and the use of an Internet-based reporting and data-sharing system—with appropriate privacy safeguards—has also been used successfully in acute care.[19,20]

The most important results of this study are the descriptive data on ETI success. Because of methodologic shortcomings inherent to our study design (see the following discussion), the physiologic data we recorded and reported should be deemphasized as "softer" endpoints. In a large group of patients in whom mostly "traditional" direct laryngoscopy and oral ETI were employed (i.e., rare access to new instruments such as video laryngoscopes), CCT providers were able to achieve ETI success rates that are similar to those reported in the ED setting.[21]

In addition to simple analysis of ETI success rates, the current study attempted to follow the lead of other investigators who have shown the importance of monitoring peri-ETI physiologic derangement.[10,12,22] Many CCT programs are noting increasing crew sizes (i.e., with addition of ground-to-air transport). Most air medical crews consist of individuals with concentrated experience in ETI. However, larger crew sizes and diminishing opportunities for ETI training and practice in the operating room could potentially mean that "successful" ETIs are requiring multiple attempts and incurring physiologic derangement. On the other hand, it is also possible that one of the very reasons for multiple attempts is that CCT crews are increasingly understanding the preference to abort an ETI attempt and reoxygenate the patient prior to a repeat pass.

Limitations and Future Research

Unfortunately, there is no "gold standard" in terms of being able to know the actual physiologic picture attendant to airway management. For some variables, data are frequently unavailable (e.g., end-tidal carbon dioxide [$ETCO_2$] was documented in only two-thirds of our data set). For other variables, such as blood pressure, there is no continuous monitoring. The fact that these parameters are assessed only a few times in the peri-ETI period means that significant alterations may go undetected. Even for variables that are monitored on a continuous basis, there may be shortcomings to data quality. Since these variables include parameters that constitute a major area of focus for the current study (i.e., HR and SpO_2), some exploration of the issues is warranted. These important limitations to this study, particularly with respect to SpO_2, reduce the ability to draw concrete conclusions from our data.

The biomedical equipment available to CCT providers allows for continuous monitoring, recording, and reporting of SpO_2. In most cases, the SpO_2 tracking is reliable and the reported numbers are simply transcribed by the CCT crews onto the patient care record (PCR). In some cases, however, the SpO_2 tracing is felt by the crews to be an inaccurate representation of the "truth" because of poor "tracking" of the SpO_2 number (e.g., if the SpO_2 device is indicating an HR different from that seen with other monitors). Acceptance of the SpO_2 device's reported number is thus occasionally problematic, particularly in the prehospital arena. Unfortunately, in the patients in whom peri-ETI hypoxemia tends to be a major concern, there is a relative increase in the likelihood of coexisting situations (e.g., shock), rendering the SpO_2 tracing quality questionable. For these reasons, and to avoid having inaccurately "low" SpO_2 readings documented on the PCR, the CCT programs involved in this study asked crews to continuously follow SpO_2 during airway management (as per preexisting protocols) and document the lowest peri-ETI number.

The practice of having CCT crews exercise some judgment in defining the SpO_2 nadir as the lowest "reliable" value occurring during ETI may or may not be the best way to go about assessing and documenting hypoxemia. Other investigators[11] have found that prehospital crews may often be unaware of (and their documentation fails to reflect) peri-ETI hypoxemia. There is thus the nontrivial risk either that the crews involved in the current study were unaware of hypoxemia or that crews' subjectivity tended to overcall "SpO_2 tracking unreliability" when the numbers were clinically unfavorable. In the absence of real-time arterial sampling, probably accompanied by investigators' presence during transports, it is difficult to know how many cases of low SpO_2 may have been missed or incorrectly designated as unreliable. The authors believe that the reliability of the hypoxemia results in this study was maximized by strict SpO_2 nadir definition and associated educational interventions, but it must be acknowledged that the lack of a gold-standard mechanism for assessing peri-ETI hypoxemia (and HR changes) represents a significant study limitation.

The preceding discussion addresses the continuously monitored variables SpO_2 and HR. It should be clearly noted that in most of the patients in this cohort, there was no continuous arterial blood pressure monitoring, so the hypotension results in this study represent only those instances of hypotension that were assessed and detected during standard peri-ETI vital sign monitoring.

With the preceding caveats in mind, the analysis of the prospectively collected available data does not reveal alarming problems with peri-ETI physiologic parameters. For the cases where peri-ETI SpO_2 was available and seemingly reliable, development of new abnormalities was rare.

One of the few statistically significant findings in the study was the association of the ETI setting with the need for multiple attempts at airway management. The lack of difference in ETI success rates achieved in the hospital, on-scene, or transport settings is consistent with the results in previous reports.[15,23] However, as investigators have been noting for a decade, it must be emphasized that these findings are likely impacted by selection bias.[15] Air medical crews will be more likely to perform intubations in the pretransport setting if the intubations are perceived to be potentially difficult. The equal success rates most likely represent the ability of CCT crews to *impose* selection bias, and defer to the in-flight setting only those ETIs that will be easy.

The constraints of the intratransport ETI setting do seem to have caused an increased need for more than one ETI attempt in order to achieve successful tube placement. Fortunately, these multiple attempts do not appear (based on our study results) to have been associated with the development of new hypoxemia or hypotension. However, the suggestion of increased requirement for multiple ETI attempts in the in-transport setting may inform decision making as CCT crews generate patient-specific stabilization and transport plans.

The ability to draw definitive conclusions from these data is limited by a number of shortcomings to our methodology. While some of our study limitations are intrinsic to the type of large-scale analysis we conducted, these limitations must still be recognized. The discussion on peri-ETI physiology included mention of the problem of incomplete or potentially biased data on some parameters. Other data were also incomplete, either because they were collected inconsistently by a given CCT service or because the data were not assessed at all by some services. The question of missing data is important to address, because it limited the study questions that could be addressed by this analysis. Data that are included in Table 1 were collected by all participating programs. Thus, for the variables outlined in the table—which comprise the focus of this report's analyses—there were no variables that were consistently not collected because of their not being reported by a participating service. In fact, the only study variable of importance that was "missing" at a significant rate was SpO_2. Unfortunately, even mathematical techniques will not provide an answer to the problem that in the prehospital setting (especially in some of the cold-weather settings in which this study was conducted), pulse oximetry is often simply unobtainable.

In addition to the problem of missing data, other accuracy problems are inherent to a study such as ours. It is possible that because data were self-reported, there were undetected inaccuracies or incomplete aspects to data submission.

We were not able to assess or adjust for some of the most important factors related to ETI performance. For instance, available evidence suggests an association between prehospital ETI success and the operator's level of training and clinical capabilities.[9] Although it is true that CCT personnel tend to benefit from more intensive initial and ongoing training than ground EMS personnel receive,[4,16,24] this remains a generalization. It would be desirable to know, for each intubation, the levels of operator experience.

This study did not address the most important outcome data relating to intubation: the clinical effects on outcome. Some studies that have found worse ETI-associated outcomes for ground provider–intubated patients have suggested that the trend is reversed (i.e., outcome is improved) when prehospital airway management is executed by helicopter emergency medical services (HEMS) CCT-level personnel.[1,25] Further research should explore the extent to which CCT-performed ETI improves outcome in various patient populations.

An additional area for further study is the use of improved devices aimed at peri-ETI physiologic monitoring. It is surely the case that peri-ETI physiologic derangement is at least as important as, if not far more so than, a simple "tick-mark" of ETI success or failure. The importance of the SpO_2 nadir has been stressed as an important airway management variable, and data have also demonstrated the criticality of maintaining appropriate ventilation (i.e., $ETCO_2$ levels).[25–12] Given the criticality of airway management, improved peri-ETI physiologic tracking is an important goal for future work. This physiologic tracking will contribute to the impact of any follow-up studies, which should strive to elucidate associations between CCT airway management techniques and patient outcomes.

Conclusion

CCT crews' ETI success rates were very high, rivaling those reported for the acute care in-hospital setting. While multiple attempts at ETI are more likely for intratransport airway management, the performance of multiple attempts did not appear to be associated with physiologic derangement. Peri-ETI deterioration of the most commonly tracked vital sign, SpO_2, was so rarely documented that this study did not identify particular areas for educational focus in this arena.

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