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Factors Associated With Oxy-hemoglobin Desaturation During Rapid Sequence Intubation in a Pediatric Emergency Department: Findings From Multivariable Analyses of Video Review Data

Andrea S. Rinderknecht, MD, Matthew R. Mittiga, MD, Jareen Meinzen-Derr, PhD, MPH, Gary L. Geis, MD, and Benjamin T. Kerrey, MD, MS

Division of Emergency Medicine (ASR, MRM, GLG, BTK), Division of Biostatistics and Epidemiology (JM), Center for Simulation and Research (GLG, BTK), Cincinnati Children's Hospital Medical Center and University of Cincinnati College of Medicine, Cincinnati, OH

Abstract

Objectives—In a video-based study of rapid sequence intubation (RSI) in a pediatric emergency department (PED), 33% of children experienced oxy-hemoglobin desaturation ($\text{SpO}_2 < 90\%$). To inform targeted improvement interventions, we planned multivariable analyses to identify patient and process variables (including time-based data around performance of key RSI process elements uniquely available from video review) associated with desaturation during pediatric RSI.

Methods—These were planned analyses of data collected during a retrospective, video-based study of RSI in a high-volume, academic PED. For variables with plausible associations with desaturation, multiple logistic regression and generalized estimating equations were used to identify those characteristics independently associated with desaturation at both the patient and attempt levels.

Results—The authors analyzed video data from 114 patients undergoing RSI over 12 months. Desaturation was more common in patients 24 months of age and younger (59%) than in patients older than 24 months of age (10%). Variables associated with desaturation in patients 24 months of age and younger were duration of attempts (both individual and cumulative), the occurrence of esophageal intubation, a respiratory indication for intubation, and young age. The receiver operating characteristics curve for the model had an area under the curve of 0.80 (95% CI = 0.67 to 0.92). Forty-six percent of desaturations occurred after 45 seconds of laryngoscopy, and 82% after 30 seconds. The odds ratio for desaturation on individual attempts lasting longer than 30 seconds (vs. those 30 seconds or less) was 5.7 (95% CI = 2.26 to 14.36).

Conclusions—For children 24 months of age or younger undergoing RSI in a PED, respiratory indication for intubation, esophageal intubation, and duration of laryngoscopy (both individual and

Corresponding Author (Reprint Requests): Andrea Rinderknecht, MD, Cincinnati Children's Hospital Medical Center, 3333 Burnet Avenue, ML2008, Cincinnati, OH, 45229-3039; Phone: 513-636-2918; Fax: 513-636-7967, andrea.rinderknecht@cchmc.org.

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cumulative) were associated with desaturation; the number of attempts was not. Interventions to limit attempt duration in the youngest children may improve the safety of RSI.

INTRODUCTION

In a video-based study of rapid sequence intubation (RSI) in a high-volume pediatric emergency department (PED), we found that the process and outcomes of this critical procedure were suboptimal.¹ Almost two-thirds of patients had at least one adverse effect during RSI. Oxy-hemoglobin desaturation ($\text{SpO}_2 < 90\%$) occurred for a third of patients, half of whom experienced more than one episode. For patients with available data, one third experienced $\text{SpO}_2 < 60\%$. Our findings suggested that desaturation during RSI for children may be more common than previously reported.²

Improving the performance and safety of RSI requires understanding patient, process, and provider characteristics associated with desaturation and other adverse effects. Several studies have reported analyses of adverse effects during emergency intubation,^{3–9} but each has significant limitations. First, most used a composite outcome of “adverse effect,” grouping outcomes such as esophageal intubation, dental injury, and desaturation, which do not likely share a causal pathway.^{3,4,6–8} Second, nearly all used data collected by self-report or chart review.^{3–8} In our experience, these type of data are often incomplete in comparison with video review, and are inadequate to calculate accurate time intervals. Third, to our knowledge, no study of the adverse effects during intubation of ED patients has included time-based variables such as the duration of RSI, or laryngoscopy attempts.

RSI is the method by which the majority of patients in prehospital, emergency, and critical care settings are intubated.^{8,10,11} In a PED, patients undergoing RSI are typically at the younger end of the pediatric age spectrum, critically ill or injured, and have acute and/or chronic cardiorespiratory illnesses. Prevention of secondary injury is of particular importance for these vulnerable patients. Hypoxia is a recognized cause of secondary injury during resuscitation,^{12,13} and can be the harbinger of more profound physiologic deterioration, including pulseless arrest.¹⁴

Our original findings suggest a need for further study and analyses of the characteristics associated with desaturation during RSI. Analyses based on data collected by video observation allow for the inclusion of time-based variables, and could be used both to inform targeted improvement efforts and to provide a firmer evidence base for current recommendations for standard RSI intervals.¹⁵ The goal of the current study was to identify patient and RSI process characteristics, including time-based variables, associated with desaturation during RSI.

METHODS

Study Design

This was a planned analysis of data collected during a previous study, which used video review as the primary method of data collection. Our protocol was approved by our institutional review board prior to study commencement.

Study Setting and Population

The study setting was the resuscitation area of an academic, high-volume PED that routinely treats patients through 21 years of age. A designated team led by a physician board certified in pediatric emergency medicine (PEM) or a third year PEM fellow manages all patients in this area, where all intubations in our PED are performed.

Any patient undergoing RSI in our PED during the study period (April 2009 through March 2010) was eligible for inclusion. Using our institution's electronic health record, we identified all patients evaluated in the resuscitation area during a 12-month period, and through manual review identified all patients who underwent RSI. We defined RSI as the administration, in rapid succession, of sedative and neuromuscular blocking medications to facilitate endotracheal intubation.¹⁵

Study Protocol

We used video review as the primary method of data collection. From a single, ceiling mounted digital video camera, video and audio are recorded continuously in each of the four bays in the resuscitation area. For patients who underwent RSI, one of three investigators, all board-certified in PEM, collected video data using a proprietary software program (VideoSphere, March Networks, Ottawa, Canada). To allow an assessment of the reliability of video review, a second investigator independently collected data from 12% of subject videos selected via a random number generator. For dichotomous data, we calculated the percent agreement between reviewers and the corresponding kappa statistic (95% confidence interval [CI]). For continuous and discrete data of sufficient range, we used Kendall's tau to assess the correlation of paired observations.

We collected data for numerous patient, process, and intubating provider characteristics, as well as the occurrence of desaturation and other adverse effects such as esophageal intubation. In our previous study, the variable "diagnostic category" was based on the primary diagnosis assigned to the subject on discharge from the ED, and was used to describe and categorize the type of patient and problem that brought him or her to the ED. The variable "indication for tracheal intubation" was defined by consensus review of the study investigators, using a modification of a published schema.¹⁶ Our determination of the indication for intubation was based on the team's reason to intubate, as verbalized on video review. When the indication for intubation was not clearly stated on the video, we assigned indications based on data available, including but not limited to hypoxia prior to intubation and significant hypercarbia ($p\text{CO}_2 > 70$ mm Hg on venous blood gas). When more than one indication was noted, we rank ordered them by consensus review. Process characteristics included the outcome (success or failure) and duration of each attempt. We defined an attempt as the insertion of a laryngoscope blade into a patient's mouth with the intent of attempting endotracheal tube (ETT) insertion, and the duration of RSI as the period from the administration of the sedative to the insertion of the ETT on the final, successful attempt. We defined a successful attempt as video evidence of any combination of the following: clinical confirmation, positive end-tidal carbon dioxide measurement, or patient stability following the apparent placement of an ETT distal to the glottis.

Outcome Measures

Our main outcome was the occurrence of oxy-hemoglobin desaturation during RSI, defined as peripherally measured saturation dropping to less than 90% during RSI. As we had no access to continuously measured vital signs, we primarily relied on video evidence of desaturation (resuscitation team verbalizing saturation dropping to less than 90% during RSI).

Data Analysis

For variables of interest and the outcome, we tabulated data and generated standard descriptive statistics. We examined how each continuous variable was distributed to determine appropriate measures of central tendency and distribution. For nominal variables with many categories, such as indication for intubation and diagnostic category, we collapsed categories to increase power and interpretability of our findings.

We constructed two models of desaturation during RSI. For the first model, the unit of analysis was the patient, and the outcome was the first desaturation episode. For the second, the unit of analysis was the individual laryngoscopy attempt, and the outcome was desaturation on that attempt. We selected candidate variables for each analysis based on the plausibility of their associations with desaturation. During construction of both models, we found significant interaction between age and time-based variables. As most desaturations occurred in patients younger than 24 months of age, and to avoid an interaction term, we only used data from this younger age group to construct the final models.

For the first model, we used multivariable logistic regression to analyze desaturation per patient. The measure of association was an odds ratio (OR) for desaturation, with a 95% CI. We initially evaluated 14 candidate variables. For time-based variables, only data up to the first desaturation were included, if one occurred. From the variables associated with desaturation at $p < 0.2$, we used manual selection methods at $p < 0.1$ to develop a final, parsimonious model. We assessed the goodness-of-fit of the final model using the Hosmer-Lemeshow test as well as model diagnostics. Finally, we constructed a receiver operator characteristic (ROC) curve and used the corresponding area under the curve (AUC) to estimate the ability of the model to discriminate between patients with and without desaturation.

For the second model, to account for the repeated measures/non-independent nature of a per attempt analysis, we used generalized estimating equations (GEE) to analyze desaturation per attempt. We employed GEE with a binary distribution and a logit link function, producing an OR as the measure of association. This model was constructed similarly to the per-patient model, including variables associated with desaturation at $p < 0.2$, then using manual variable selection methods and $p < 0.1$ to construct the final, parsimonious model.

As duration of laryngoscopy remained in both final models, we performed post hoc analyses to define a specific duration of laryngoscopy after which patients were at increased risk of desaturation. Starting with the median duration of successful laryngoscopy attempts, we evaluated cut points for the duration of laryngoscopy per attempt, in 15 second increments. We replaced the continuous variable “duration of laryngoscopy” in the second model with

each dichotomous cut point, to assess each cut point's ability to predict desaturation. We then calculated ORs for desaturation at each cut point. All statistical analyses were performed using SAS (version 9.3).

RESULTS

We analyzed video data for 114 of 123 eligible subjects (93%) undergoing RSI in our PED during the 12-month study period. Nine videos were unavailable for review because of automated deletion from the secured drive. As reported in our original study,¹ few data were missing for any variable, and measures of inter-rater reliability were high. A second reviewer collected data for 14 subjects. Agreement was 100% and the kappa statistic was 1.0 for first-attempt success. Reviewer agreement was 93%, with a kappa of 0.85 (95% CI = 0.57 to 1.0), for the occurrence of both desaturation and bradycardia during RSI. For most time points, including the times of first sedative administration, first laryngoscopy, and the final securement of the ETT, Kendall's tau was at least 0.97.

Characteristics of Study Subjects and Attempts

Table 1a presents characteristics of the 114 patients in our sample. Nearly half of the sample was 24 months of age or younger. Patients in this younger group had a lower median weight; were more often being resuscitated for medical (versus traumatic) etiologies; and were more likely to have respiratory indications for intubation, longer total durations of RSI, and a lower percentage of first-attempt success.

Table 1b presents characteristics of the 221 attempts performed for the 114 patients. Figures 1a and 1b present the distribution of durations of individual attempts and intubating provider types. The median duration for all attempts was 35 seconds (IQR 24 to 55 seconds, range 3 to 208 seconds). Thirteen attempts lasted longer than 90 seconds. For those attempts where an ETT was placed successfully, the median duration was 32 seconds (IQR 22 to 47 seconds, range 8 to 119 seconds). The probability of successful ETT placement decreased steadily with longer attempt duration. Of 86 attempts lasting 30 seconds or less, 52 (61%) ended in successful placement of an ETT on that attempt. The success rate was 46% for attempts lasting 30 seconds or longer (135 attempts), 42% for those lasting 45 seconds or longer (74 attempts), 36% for those lasting 60 seconds or longer (42 attempts), and 25% if the attempt lasted longer than 75 seconds (24 attempts).

Primary Outcome

One-third of patients in the study sample experienced at least one episode of desaturation. Desaturation occurred for 32 of 54 patients 24 months of age or younger (59%), compared with 6 of 60 older patients (10%) (Table 2). Desaturation was noted during 57 of the total 221 attempts (26%), occurring on 50 of the 116 attempts (43%) performed on patients 24 months of age or younger, and seven of 105 attempts (7%) performed on older patients.

Table 3 displays the variables initially considered for the per-patient model. The final model of the first desaturation during RSI for patients 24 months included four variables: cumulative duration of laryngoscopy, esophageal intubation, a respiratory indication for intubation, and patient age (Table 4a). The ROC curve for the model had an AUC of 0.80

(95% CI = 0.67 to 0.92). Figure 2 illustrates the estimated probability of desaturation with increasing age when the model is applied to all patients in our sample.

Table 5 presents the attempt level characteristics initially considered for the second model. The final model of desaturation per attempt included three variables: total duration of RSI, esophageal intubation, and the duration of the individual attempt (Table 4b). The 95% CIs for the ORs for all three variables excluded one.

Figures 3a and 3b show the ORs for a first desaturation episode for various durations of cumulative laryngoscopy time and individual attempt time. For 30 seconds of cumulative laryngoscopy (compared with a reference of 1 second), the odds of desaturation were 2.2. For 90 seconds, the odds rose to 10.8. For an individual attempt lasting 30 seconds, the odds of desaturation were 2.0. For 90 seconds, the odds rose to 7.7. The estimated probability of desaturation increased with increasing individual laryngoscopy attempt duration (Figure 4).

Eighty-two percent of all desaturations occurred after 30 seconds of laryngoscopy time, 46% of all desaturations after 45 seconds, and 26% after 60 seconds. The rate of desaturation during attempts lasting 30 seconds was 21.4%, increasing to 57% on attempts lasting longer than 30 seconds. After replacing the continuous variable (duration of laryngoscopy) with a dichotomous variable of duration $\leq$ or $>$ 30 seconds in the second model (controlling for total duration of RSI and esophageal intubation), the OR for desaturation on individual attempts lasting longer than 30 seconds (compared with 30 seconds or less) was 5.7 (95% CI = 2.26 to 14.36).

DISCUSSION

In this video-based study of RSI in an academic PED, the majority of patients experiencing desaturation were 24 months of age or younger. For these patients, multivariable analysis of desaturation, at the patient and attempt levels, suggested that the individual and cumulative duration of laryngoscopy, rather than the number of attempts, was associated with desaturation. More than half of attempts lasting $>$ 30 seconds were associated with desaturation, which was almost six times more likely when compared to those lasting 30 seconds or less. Esophageal intubation and respiratory indication for intubation were also found to be associated with desaturation.

Our study results support existing theories around patient and process factors thought to be associated with desaturation. For instance, younger age, a recognized risk factor for complications during emergency intubation,¹⁵ was strongly associated with the risk of desaturation in our study. We also found that a respiratory indication for intubation (i.e., failure of ventilation or oxygenation) was associated with desaturation during RSI. Acute and/or chronic respiratory illnesses limit the effectiveness of oxygenation during any phase of intubation, and may further limit the functional residual capacity. Interventions that could help mitigate the risks associated with ventilation or oxygenation failure include maximizing oxygen delivery throughout RSI through effective pre-oxygenation before the first attempt, apneic oxygenation during all attempts, and adequate re-oxygenation after failed attempts.¹⁷

An ETT placed in the esophagus prevents effective oxygenation and ventilation, potentially for a prolonged period of time if not immediately identified, and was found to be significantly associated with the risk of desaturation in our study. Esophageal intubation may be more common in settings like ours, where trainees perform the majority of attempts. Traditionally, only the provider performing laryngoscopy can see the airway as the endotracheal tube is inserted. A potential intervention to limit the risk of esophageal intubation is the use of supervised video laryngoscopy, where the video screen is used by the supervising physician or care team, allowing cross-checking of the approach to airway visualization, direct confirmation of ETT placement, and improved team situational awareness during an attempt. If esophageal intubation does occur, immediate use of capnography for confirmation limits the duration of ineffective ventilation.

Our study also adds new evidence to the existing body of work around the safe practice of RSI. Two studies from the neonatology literature have reported the duration of laryngoscopy attempts during the intubation of critically ill or injured patients.^{18,19} Both of these studies relied on video review for data collection. The association between the duration of various intervals, including laryngoscopy, and the risk of adverse effects during RSI has not been well studied. We found three intervals to be associated with desaturation during RSI: the total duration of RSI, and both the cumulative, and individual duration of laryngoscopy attempts. Cumulative duration of laryngoscopy and total RSI duration were highly correlated and essentially interchangeable in our first model. The total duration of RSI consists of laryngoscopy time and non-laryngoscopy time, the downtime between attempts during which tasks such as medication administration, re-oxygenation, and repositioning occur. We do not know why non-laryngoscopy time would increase the risk of desaturation, as oxygen delivery to the patient should be relatively uninterrupted outside of laryngoscopy attempts. Although we posit that laryngoscopy time is responsible for the majority of the risk associated with a longer total duration of RSI, streamlined standardization of the RSI process, as with a checklist, might lower any risk associated with a longer non-laryngoscopy time.

Despite being reported in many previous studies to have an association with adverse effects during emergency intubation,^{3,5-7,20} we found no independent association between the number of laryngoscopy attempts and desaturation. This may have to do with the small number of patients in the analysis. However, previous studies have not had the capability to assess or report the duration of attempts. We believe that multiple attempts may have an indirect association with desaturation by increasing the number of opportunities for a prolonged attempt, as well as the cumulative duration of attempts. Although we commonly observed providers limiting the number of attempts a trainee can perform, it was not our experience that providers limited the duration of laryngoscopy before desaturation occurred. The editorial response to the publication of our initial study discussed improving laryngoscopy and intubation skills of providers performing emergency intubation as a leading approach to improve the safety of RSI.²¹ Although we agree that improving the skill of laryngoscopists in the PED is important, we believe it may not be the most feasible way to improve safety and outcomes of RSI in the pediatric setting. Our findings suggest a potential paradigm shift for how to keep patients safe during emergency intubation when less proficient or below-mastery level providers are attempting intubation. Placing external

controls on the maximum allowable duration of laryngoscopy and maximizing oxygenation between attempts, rather than limiting the number of attempts themselves, may have a greater effect on the safety of this critical procedure than efforts to improve and maintain the laryngoscopy and intubation skills for providers who will continue to perform the procedure infrequently based on its relative rarity in the PED setting.

There are few expert opinion recommendations for the durations of various RSI intervals. Neonatal Resuscitation Program guidelines, developed primarily for the resuscitation of neonates in a delivery room, suggest that the “tracheal intubation procedure” should be completed within 30 seconds.²² The suggested duration from the time of administration of sedative and paralytic medications through confirmation of ETT position from the Manual of Emergency Airway Management is 60 seconds.¹⁵ However, no data-driven recommendations exist to guide practitioners around specific process components and time elements, especially the duration of individual laryngoscopy attempts. Knowing that “longer attempts are worse” does not help the clinician at the bedside. More specific guidance in the form of an accurately defined cut-off at which the duration of a laryngoscopy attempt puts the patient at greater risk for adverse effects is required. Our use of video review allowed us to provide the first time-based data collected from children undergoing RSI to answer this question. Based on our analyses, limiting the duration of individual laryngoscopy attempts ideally to 30 seconds, but 45 seconds at the most in children 24 months of age or younger, would help prevent the majority of desaturations in this population. We do not believe limiting laryngoscopy attempts to these durations would negatively affect success on these attempts, as we provide data to suggest that longer attempt duration is not associated with improved success.

In the summer of 2012, we began a formal quality improvement effort to decrease the occurrence of desaturation during RSI in our ED. Our ongoing efforts support the effectiveness of the above suggested targeted interventions in reducing desaturation. By addressing certain process elements including standardization of practice, supervision of trainees through the use of a video laryngoscope, and limitation of laryngoscopy attempts to 45 seconds, we have reduced desaturation by 50% while not intervening on laryngoscopy skill (unpublished data).

Based on our experience using video review to study the performance and safety of RSI, we strongly believe that any future studies in this area should: 1) account for data at both the patient and attempt levels, 2) use theory and physiologic plausibility to select the variables analyzed, 3) use specific individual outcomes rather than composite “adverse effects” that do not share a common causative pathway, and 4) include time-based variables. To do this reliably, either video review or direct observation with access to continuously measured vital signs should be used.

LIMITATIONS

The results of the current study should be interpreted in light of several limitations. First, our sample size was small, limiting our ability to identify factors with weaker associations with desaturation. The restriction of our final analyses to the youngest patients compounded this

problem. Mitigating the limits of our small sample size were our nearly consecutive sample from a 12-month period, and our use of video review for data collection. Second, as we had no access to continuously measured vital signs (primary data), we relied on video evidence of desaturation (secondarily derived data). This likely led to underreporting of desaturation events, although most likely of less severe or self-limited episodes. More importantly, in lacking primary continuous vital sign data, we were forced to treat desaturation as a dichotomous rather than continuous variable, limiting our ability to differentiate minor from more serious episodes of desaturation for the analyses. Third, although planned, our model building was largely exploratory, with a liberal statistical cut-off for variable inclusion. We chose this cut-off in part because of the limits of our sample size. Mitigating this limitation was our inclusion of variables in both models according to the plausibility of their associations with the outcome. Finally, our approach limits the generalizability of our findings to patients older than 24 months. Older patients in a PED appear to be at far lower risk of desaturation, and different factors may lead to desaturation in this group. However, we feel that any efforts to improve the process and outcomes of RSI for the younger group based on our findings could easily be extrapolated to all patients to reduce variability in practice and make the practice of RSI safer for all pediatric patients in any ED setting.

CONCLUSIONS

Through multivariable analyses of data collected by video review, we found that for children < 24 months of age undergoing rapid sequence intubation in an academic pediatric ED, a respiratory indication for intubation, the occurrence of esophageal intubation, and the individual and cumulative duration of laryngoscopy attempts were associated with desaturation; the number of attempts was not. Given the challenges of improving laryngoscopy and intubation skill of providers, efforts to improve the safety of rapid sequence intubation in a pediatric ED may need to be focused on recognizing the patients at highest risk (young, and with respiratory indications for intubation), standardizing and streamlining the rapid sequence intubation process, minimizing the risk of esophageal intubation, and limiting individual attempt duration.

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References

1. Kerrey BT, Rinderknecht AS, Geis GL, Nigrovic LE, Mittiga MR. Rapid sequence intubation for pediatric emergency patients: higher frequency of failed attempts and adverse effects found by video review. *Ann Emerg Med.* 2012; 60:251–9. [PubMed: 22424653]
2. Sagarin MJ, Chiang V, Sakles JC, Barton ED, Wolfe RE, Vissers RJ, Walls RM. National Emergency Airway Registry (NEAR) investigators. Rapid sequence intubation for pediatric emergency airway management. *Pediatr Emerg Care.* 2002; 18(6):417–23. [PubMed: 12488834]

3. Choi HJ, Je SM, Kim JH, Kim E. The factors associated with successful paediatric endotracheal intubation on the first attempt in emergency departments: a 13 emergency department registry study. *Resuscitation*. 2012; 83(11):1363–8. [PubMed: 22429973]
4. Hasegawa K, Shigemitsu K, Hagiwara Y, et al. Association between repeated intubation attempts and adverse events in emergency departments: an analysis of a multicenter prospective observational study. *Ann Emerg Med*. 2012; 60:749–54. [PubMed: 22542734]
5. Mort TC. Emergency tracheal intubation: complications associated with repeated laryngoscopic attempts. *Anesthes Analg*. 2004; 99:607–13.
6. Griesdale DE, Bosma TL, Kurth T, Isac G, Chittock DR. Complications of endotracheal intubation in the critically ill. *Intensive Care Med*. 2008; 34:1835–42. [PubMed: 18604519]
7. Carroll CL, Spinella PC, Corsi JM, Stoltz P, Zucker AR. Emergent endotracheal intubations in children: be careful if it's late when you intubate. *Pediatr Crit Care Med*. 2010; 11:343–8. [PubMed: 20464775]
8. Nishisaki A, Ferry S, Colborn S, et al. Characterization of tracheal intubation process of care and safety outcomes in a tertiary pediatric intensive care unit. *Pediatr Crit Care Med*. 2012; 13:e5–10. [PubMed: 21057359]
9. Nett S, Emeriaud G, Jarvis JD, Montgomery V, Nadkarni VM, Nishisaki A. Site-level variance for adverse tracheal intubation-associated events across 15 North American PICUs: a report From the National Emergency Airway Registry for Children*. *Pediatr Crit Care Med*. 2014; 15:306–13. [PubMed: 24691538]
10. Sagarin MJ, Barton ED, Chng YM, Walls RM. Airway management by US and Canadian emergency medicine residents: a multicenter analysis of more than 6,000 endotracheal intubation attempts. *Ann Emerg Med*. 2005; 46:328–36. [PubMed: 16187466]
11. Wang HE, Kupas DF, Paris PM, Bates RR, Yealy DM. Preliminary experience with a prospective, multi-centered evaluation of out-of-hospital endotracheal intubation. *Resuscitation*. 2003; 58:49–58. [PubMed: 12867309]
12. Chesnut RM, Marshall LF, Klauber MR, et al. The role of secondary brain injury in determining outcome from severe head injury. *J Trauma*. 1993; 34:216–22. [PubMed: 8459458]
13. Chi JH, Knudson MM, Vassar MJ, et al. Prehospital hypoxia affects outcome in patients with traumatic brain injury: a prospective multicenter study. *J Trauma*. 2006; 61:1134–41. [PubMed: 17099519]
14. Heffner AC, Swords DS, Neale MN, Jones AE. Incidence and factors associated with cardiac arrest complicating emergency airway management. *Resuscitation*. 2013; 84:1500–4. [PubMed: 23911630]
15. Walls, RM.; Murphy, MF., editors. *Manual of Emergency Airway Management*. 3. New York, NY: Lipincott, Williams, and Wilkins; 2008.
16. Nishisaki A, Donoghue A, Colborn S, et al. Effect of just-in-time simulation training on tracheal intubation procedure safety in the pediatric intensive care unit. *Anesthesiology*. 2010; 113:214–23. [PubMed: 20526179]
17. Weingart SD, Levitan RM. Preoxygenation and prevention of desaturation during emergency airway management. *Ann Emerg Med*. 2012; 59:165–75. [PubMed: 22050948]
18. O'Donnell CP, Kamlin CO, Davis PG, Morley CJ. Endotracheal intubation attempts during neonatal resuscitation: success rates, duration, and adverse effects. *Pediatrics*. 2006; 117:e16–21. [PubMed: 16396845]
19. Lane B, Finer N, Rich W. Duration of intubation attempts during neonatal resuscitation. *J Pediatr*. 2004; 145:67–70. [PubMed: 15238909]
20. Sakles JC, Chiu S, Mosier J, Walker C, Stolz U. The importance of first pass success when performing orotracheal intubation in the emergency department. *Acad Emerg Med*. 2013; 20:71–8. [PubMed: 23574475]
21. Green SM. A is for airway: a pediatric emergency department challenge. *Ann Emerg Med*. 2012; 60:261–3. [PubMed: 22520991]
22. Zaichkin, J.; Kattwinkel, J.; McGowan, J. American Heart Association, American Academy of Pediatrics. *Textbook of Neonatal Resuscitation*. 6. Elk Grove Village, IL: American Academy of Pediatrics; 2011. p. 1online resource (xiii)

Figure 1.

Figure 1a. Duration of Individual Laryngoscopy Attempts

Figure 1b. Duration of Individual Laryngoscopy Attempts by Provider Type

217 of 221 total attempts depicted. Two attempts had missing data for laryngoscopy duration, and 2 attempts lasting 171 (faculty performing) and 208 seconds (pediatric resident performing), were omitted from the Figures for clarity.

Figure 2. Estimated probability of desaturation during rapid sequence intubation as a function of age from a logistic regression model applied to the entire study sample (n = 114)

Figure 3.

Figure 3a. Change in odds ratio (OR) and 95% CI for desaturation during rapid sequence intubation with increasing cumulative laryngoscopy attempt duration

LCL = lower confidence level; UCL = upper confidence level; Compared to reference of 1 second

Figure 3b. Change in odds ratio (OR) and 95% CI for desaturation during rapid sequence intubation with increasing individual laryngoscopy attempt duration

LCL = lower confidence level; UCL = upper confidence level Compared to reference of 1 second

Figure 4.

Estimated probability of desaturation during rapid sequence intubation as a function of individual laryngoscopy attempt duration during 116 attempts for 54 subjects 24 months undergoing RSI over 12 months

Dashed lines represent 30 and 45 second cutoffs for laryngoscopy duration

Table 1a

Patient and process characteristics for 114 patients undergoing RSI over a 12-month period

Characteristic	All (N=114)	24 months (n=54)	>24 months (n=60)
Age (yrs)	2.4 (0.4–10.1)	0.3 (0.12–1.03)	9.7 (5.7–15.4)
Weight (kg)	13 (5.7–38)	5.5 (3.4–10.0)	37.0 (19–67.5)
PRISM II (n = 110)	6 (2–12)	8 (5–14)	4 (1–8)
Medical resuscitation	89 (78)	50 (93)	39 (65)
Respiratory indication*	61 (54)	38 (70.4)	23 (38.3)
Diagnostic category			
Neurologic	39 (34)	15 (28)	24 (40)
Respiratory	29 (25)	23 (43)	6 (10)
Shock	13 (11)	10 (19)	3 (5)
Trauma	21 (18)	5 (9)	16 (26.7)
Other	12 (11)	1 (2)	11 (18.3)
Adequate pre-oxygenation†	86 (77)	43 (80)	43 (71.7)
RSI duration‡	182.5 (112–441)	247 (130–505)	156 (96.5–302)
Attempt > 45 sec§	56 (49.1)	29 (53.7)	27 (45)
Cumulative laryngoscopy time¶	112.5 (69–161)	106 (69–161)	124.5 (80.5–165)
NMB re-dosed	19 (16.7)	12 (22.2)	7 (11.7)
Esophageal intubation	19 (16.7)	11 (20.4)	8 (13.3)
Number of attempts	1 (1–3)	2 (1–3)	1 (1–2)
1 attempt	59 (52)	22 (41)	37 (62)
2 attempts	25 (23)	13(24)	12 (20)
3 attempts	30 (26)	19 (35)	11 (18)

* Respiratory indications were oxygenation failure, ventilation failure, apnea associated with infection, and apnea associated with shock. Non-respiratory indications were head injury, seizure, altered mental status, and other.

† Adequate defined as continuous application of supplementary oxygen for at least 3 minutes; n = 111

‡ Time from administration of RSI sedative to successful placement of an endotracheal tube.

§ Number of patients experiencing at least one individual attempt at laryngoscopy lasting longer than 45 seconds.

¶ Summation of all laryngoscopy time, including on the final attempt with successful placement of an endotracheal tube.

NMB = neuromuscular blocker; PRISM II = pediatric risk of mortality score; RSI = rapid sequence intubation

Median (interquartile range) shown for continuous variables, n (%) for dichotomous or categorical variables.

Table 1b

Patient and process characteristics of 221 attempts for 114 patients undergoing RSI over a 12-month period

Characteristic	All (N=221)	24 months (n=116)	>24 months (n=105)
Age (yrs)	2.4 (0.4–10.1)	0.3 (0.12–1.03)	9.7 (5.7–15.4)
Respiratory indication*	121 (54.7)	87 (75)	34 (32.4)
NMB re-dosed [†]	21 (10)	14 (12)	7 (6.7)
Attempt success [‡]	114 (52)	54 (46.6)	60 (57.1)
Esophageal intubation [§]	26 (12)	15 (12.9)	11 (10.5)
Preceding RSI duration (sec) ^{//}	165 (89–357)	217 (113–454)	153 (86–326.5)
Preceding cumulative laryngoscopy (sec) [¶]	0 (0–59)	24 (0–61)	0 (0–58)
Duration of attempt (sec) ^{**}	35 (24–55)	44 (31–61) ^{††}	32 (23–51)

* Respiratory indications for intubation were oxygenation failure, ventilation failure, apnea associated with infection, and apnea associated with shock. Non-respiratory indications were head injury, seizure, altered mental status, and other.

[†] NMB = neuromuscular blocker, re-dosed just prior to that attempt

[‡] Successful placement of endotracheal tube (ETT) on that attempt

[§] Non-airway placement of ETT on that attempt

^{//} Cumulative duration of RSI (since administration of RSI sedative) preceding the beginning of this attempt

[¶] Cumulative laryngoscopy duration preceding the beginning of this attempt. Includes values of 0 because any 1st attempt would not have had a preceding laryngoscopy attempt. Fifty nine (52%) of the 114 patients were intubated on 1st attempt.

^{**} Duration of individual laryngoscopy attempt, from insertion of laryngoscope blade into mouth through removal of blade from the mouth; n = 219

^{††} n = 114

Median (interquartile range) shown for continuous variables, n (%) for dichotomous or categorical variables

Six patients older than 24 months of age who experienced oxyhemoglobin desaturation during RSI in a PED over 12 months

Table 2

Patient	Age (yrs)	Weight (kg)	Primary Indication for Intubation	Diagnostic Category	Number of Laryngoscopy Attempts	Duration of Attempts (sec)	Provider Type Performing Attempt	Depth of Desaturation	Clinical Information Available
1	9.4	60	Head injury	Trauma	3	19 15 8	PEM fellow PEM fellow Anesthesia	77%	Pedestrian struck by car, thrown 15 feet Special health care needs, presenting with abdominal distension. Cyanotic episode noted during observation in PED. Venous blood gas with pH 7.16, pCO ₂ 94 mm Hg.
2	23	48	Ventilation failure	Other	1	21	Pediatric resident	Not available	Pedestrian struck by car, blood in vomitus. Moderate right pneumothorax. Venous blood gas with pH 6.94, pCO ₂ 85 mm Hg. Hypotension during RSI.
3	7.4	30	Head injury	Trauma	1	29	Anesthesia	78%	Post-ictal after seizure, noted to have poor tone, upper airway obstruction, and ineffective breathing. Venous blood gas with pH 7.14, pCO ₂ 66 mm Hg.
4	7.8	30	Oxygenation failure	Neurologic	3	3 44 91	EM resident EM resident EM resident	Not available	Respiratory distress, upper airway obstruction, first saturation on arrival 80%. Underwent two unsuccessful laryngoscopy attempts (42 and 43 seconds) with sedation only (ketamine). Paralytic given prior to 3 rd attempt (1 st attempt at RSI), which was successful. Venous blood gas with pH 7.37, pCO ₂ 43 mm Hg. Hypotension noted during RSI.
5	9.8	48	Oxygenation failure	Other	1	45	Other (ENT)	Not available	Seizures. Venous blood gas with pH 7.29, pCO ₂ 57 mm Hg. Several esophageal intubations, multiple desaturations.
6	2.7	15	Seizures	Neurologic	9	64 66 96 28 69 33 56 41 45	Pediatric resident PEM attending PEM attending PEM attending PEM attending PICU fellow Anesthesia	27%	

ENT = Ear/Nose/Throat (Otolaryngology); PEM = Pediatric Emergency Medicine; PICU = Pediatric Intensive Care Unit

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Table 3

Desaturation and candidate variables for 54 patients 24 months of age undergoing RSI over a 12-month period

Variable	Desaturation (n=32)	No Desaturation (n=22)
Age (yrs)	0.43 (0.13–1.22)	0.30 (0.11–0.95)
Weight (kg)	5.7 (3.45–10)	5.1 (3.0–10)
PRISM II *	7.5 (5.0–12.5)	10 (5.0–19)
Medical resuscitation	32 (100)	18 (82)
Respiratory indication [†]	25 (78)	13 (59)
Diagnostic category		
Neurologic	10 (31)	5 (23)
Respiratory	14 (44)	9 (41)
Shock	6 (19)	4 (18)
Trauma	1 (3)	4 (18)
Other	1 (1)	0
Adequate pre-oxygenation [‡]	25 (78)	18 (82)
RSI duration (min) [§]	7.7 (4.3–11.8)	2.1 (1.9–3.0)
Attempt > 45 seconds ^{//}	21 (66)	8 (36)
Cumulative laryngoscopy time (sec) [¶]	116 (82–162) **	61 (51–69)
NMB re-dosed	12 (38)	0
Esophageal intubation ^{††}	10 (31)	1 (5)
Inadequate paralysis ^{‡‡}	2 (6)	2 (9)
Number of attempts	3 (2–3.5)	1 (1–1)
1 attempt	5 (16)	17 (77)
2 attempts	8 (25)	5 (23)
3 attempts	19 (59)	0

* PRISM II = pediatric risk of mortality score; n = 53

[†] Respiratory indications were oxygenation failure, ventilation failure, apnea associated with infection, and apnea associated with shock. Non-respiratory indications were head injury, seizure, altered mental status, and other.

[‡] Adequate defined as continuous application of supplementary oxygen for at least 3 minutes; n = 43

[§] Time from administration of RSI sedative to successful placement of an endotracheal tube (ETT).

^{//} Any individual attempt at laryngoscopy lasting longer than 45 seconds.

[¶] Summation of all laryngoscopy time, including the final attempt with successful placement of an ETT.

** n = 30

^{††} Non-airway placement of ETT on that attempt

^{‡‡} Patient movement or vocalization during a laryngoscopy attempt

NMB = neuromuscular blocker

Median (interquartile range) shown for continuous variables, n (%) for dichotomous or categorical variables; N=54, unless specified

Table 4a

Multiple logistic regression model of at least one vs. no desaturation for 54 patients 24 months of age undergoing RSI over a 12-month period

Variable	AOR (95% CI)	p-value
Cumulative laryngoscopy time (per second increase) *	1.03 (1.002–1.05)	0.03
Respiratory indication	5.0 (0.9–26.5)	0.06
Esophageal intubation	7.1 (0.7–69.1)	0.09
Age (per year increase)	2.8 (0.8–9.4)	0.10

* We report the effect of the duration of laryngoscopy on desaturation as a continuous variable, which most accurately represents what appears to be a linear relationship (for every second increase, the odds of desaturation increases by 1.03; after 10 seconds the odds of desaturation increases by a factor of 1.34 (34% increase in the odds). A patient with a laryngoscopy time of 20 seconds has a 34% increased odds of desaturation compared to a patient with a laryngoscopy time of 10 seconds.)

AOR = adjusted odds ratio; RSI = rapid sequence intubation

Table 4b

Repeated measures model of desaturation for 116 attempts performed during RSI of 54 patients 24 months of age over a 12-month period

Variable	AOR (95% CI)	p-value
Duration of RSI (per second increase)	1.001 (1.0002–1.003)	0.018
Esophageal intubation	3.6 (1.2–10.8)	0.025
Duration of attempt (per second increase)	1.02 (1.0004–1.05)	0.046

AOR = adjusted odds ratio; RSI = rapid sequence intubation

Table 5

Desaturation and candidate variables for 116 laryngoscopy attempts performed during RSI of 54 patients 24 months of age over a 12-month period

Variable	Desaturation (50 attempts)	No Desaturation (66 attempts)
Age (yrs)	0.2 (0.1–0.8)	0.2 (0.1–1.0)
Respiratory indication*	39 (78)	48 (73)
NMB re-dosed [†]	8 (16)	6 (9)
Attempt success [‡]	17 (34)	37 (56)
Esophageal intubation [§]	11 (22)	4 (6)
Preceding RSI duration (sec) ^{//}	221 (114–521)	156 (91–343)
Preceding cumulative laryngoscopy (sec) [¶]	30.5 (0–60.5)	0 (0–51.5)
Duration of attempt (sec) ^{**}	43 (31–60)	29 (21.5–42.5)

* Respiratory indications for intubation were oxygenation failure, ventilation failure, apnea associated with infection, and apnea associated with shock. Non-respiratory indications were head injury, seizure, altered mental status, and other.

[†] NMB = neuromuscular blocker, re-dosed just prior to that attempt

[‡] Successful placement of endotracheal tube (ETT) on that attempt

[§] Non-airway placement of ETT on that attempt

^{//} Cumulative duration of RSI (since administration of RSI sedative) preceding the beginning of this attempt

[¶] Cumulative laryngoscopy duration preceding the beginning of this attempt. Includes values of 0 because any 1st attempt would not have had a preceding laryngoscopy attempt. Fifty nine (52%) of the 114 patients were intubated on 1st attempt.

^{**} Duration of individual laryngoscopy attempt, from insertion of laryngoscope blade into mouth through removal of blade from the mouth

Median (interquartile range) shown for continuous variables, n (%) for dichotomous or categorical variables