Incidence and Duration of Continuously Measured Oxygen Desaturation During Emergency Department Intubation

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Study objective: Desaturation during intubation has been associated with serious complications, including dysrhythmias, hemodynamic decompensation, hypoxic brain injury, and cardiac arrest. We seek to determine the incidence and duration of oxygen desaturation during emergency department (ED) rapid sequence intubation.

Methods: This study included adult rapid sequence intubation cases conducted between September 2011 and July 2012 in an urban, academic, Level I trauma center ED. We obtained continuous vital signs with BedMasterEX data acquisition software. Start and completion times of rapid sequence intubation originated from nursing records. We defined oxygen desaturation as (1) cases exhibiting SpO_2 reduction to less than 90% if the starting SpO_2 was greater than or equal to 90%, or (2) a further reduction in SpO_2 in cases in which starting SpO_2 was less than 90%. We used multivariable logistic regression to predict oxygen desaturation during rapid sequence intubation.

Results: During the study period, there were 265 rapid sequence intubation cases. The study excluded 99 cases for failure of electronic data acquisition, inadequate documentation, or poor SpO_2 waveform during rapid sequence intubation, and excluded cases managed by anesthesia providers, leaving 166 patients in the analysis. After preoxygenation, starting SpO_2 was greater than 93% in 124 of 166 cases (75%) and SpO_2 was less than 93% in the remaining 46 cases. Oxygen desaturation occurred in 59 patients (35.5%). The median duration of desaturation was 80 seconds (interquartile range 40, 155). Multivariable analysis demonstrated that oxygen desaturation was associated with preintubation SpO_2 less than 93% (odds ratio [OR] 5.1; 95% confidence interval (CI) 2.3 to 11.0), multiple intubation attempts (>1 attempt) (OR 3.4; 95% CI 1.4 to 6.1), and rapid sequence intubation duration greater than 3 minutes (OR 2.7; 95% CI 1.2 to 6.1).

Conclusion: In this series, 1 in 3 patients undergoing ED rapid sequence intubation experienced oxygen desaturation for a median duration of 80 seconds. Preintubation saturation less than 93%, multiple intubation attempts, and prolonged intubation time are independently associated with oxygen desaturation. Clinicians should use strategies to prevent oxygen desaturation during ED rapid sequence intubation. [Ann Emerg Med. 2015;■:1-7.]

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INTRODUCTION

Background

Rapid sequence intubation is a central technique in emergency department (ED) airway management. An important related adverse event is oxygen desaturation and resultant hypoxemia, which has been associated with dysrhythmias, hemodynamic decompensation, hypoxic brain injury, and cardiac arrest, particularly at saturations below 70%.[1-6] Clinical guidelines emphasize the importance of avoiding oxygen desaturation and hypoxemia. Both the EAST Guidelines 2012 and Brain Foundation Guidelines enforce the importance of avoiding hypoxia (SpO_2 <90%) in brain injury, pointing to an increase in morbidity and mortality.[7,8]

Importance

Despite the perceived importance of this adverse event, little is known about the true rates of desaturation during ED rapid sequence intubation. Previous studies of advanced airway management strategies, not all restricted to emergency rapid sequence intubation or emergency physicians, have reported desaturation occurring in 0.2% to 19.2% of cases.[9-16] Some of these studies reporting low desaturation rates used definitions that may have underestimated desaturation events. For example, one multicenter study reporting a less than 1% rate of desaturation excluded patients experiencing esophageal intubation.[15] Another study from an academic trauma center reporting hypoxemia in only

Editor's Capsule Summary

What is already known on this topic

Oxygenation desaturation during rapid sequence intubation is potentially harmful.

What question this study addressed

What are the incidence and characteristics of oxygen desaturation during emergency department (ED) rapid sequence intubation?

What this study adds to our knowledge

In this series using a continuous vital sign data acquisition system, oxygen desaturation (SpO_2 decrease <90%) occurred in 59 of 166 ED rapid sequence intubation cases (35.5%), with a median duration of 80 seconds.

How this is relevant to clinical practice

Clinicians should consider strategies to prevent oxygen desaturation during ED rapid sequence intubation.

1.2% of rapid sequence intubation cases excluded hypoxemic events attributed to underlying injury.[16] Studies reporting much higher rates of desaturation, 18.2% and 19.2%, included all instances of hypoxemia regardless of underlying cause.[13,14]

Previous studies of rapid sequence intubation desaturation have relied on self-reported data and thus may have missed important episodes of desaturation.[9-16] Continuously recorded oxygen saturation data can overcome this important limitation. An out-of-hospital study that used continuously recording pulse oximeters found a much higher rate of desaturation than in previous studies using self-reported values.[17]

A better understanding of the true rates of and the factors associated with oxygen desaturation during ED rapid sequence intubation could influence practice, identifying opportunities to improve rapid sequence intubation technique or the application of strategies to prevent desaturation events.

Goals of This Investigation

The goal of this study was to determine the incidence and duration of oxygen desaturation during ED rapid sequence intubation. In addition, we sought to identify factors associated with rapid sequence intubation oxygen desaturation.

MATERIALS AND METHODS

Study Design and Setting

This was an institutional review board–approved, cross-sectional survey of existing airway management practice conducted between September 2011 and July 2012 in the University of New Mexico Hospital Emergency Department, which is an urban Level I trauma center with an Accreditation Council for Graduate Medical Education–approved emergency medicine residency and a total annual volume of approximately 90,000 patients.

Standard airway practice in our ED uses rapid sequence intubation coupled with direct or video laryngoscopy performed in resuscitation or trauma rooms. Preoxygenation is typically performed with a nonrebreather mask set at 15 L/min or greater for several minutes or bag-valve-mask ventilations with supplemental oxygen at 15 L/min or greater when the patient remains hypoxemic despite a nonrebreather mask. During the study period, the use of apneic (passive) nasal oxygenation during the rapid sequence intubation attempt was not common in our ED.[1,18] Available airway devices included direct laryngoscopy with straight or curved blades and the Storz CMAC video laryngoscope (Karl Storz, El Segundo, CA) with both C and D blades. Attending emergency medicine faculty were present for all rapid sequence intubation attempts and occasionally performed intubations independently when residents were not present or after failed intubation attempts by residents.

Selection of Participants

Using electronic records from the ED automated medication management system (Pyxis MedStation; CareFusion Corp, San Diego, CA), we identified all patients for whom a paralytic medication was dispensed during the study period. We reviewed ED clinical charts and airway quality assurance data collection forms to verify that the paralytic agent was used for rapid sequence intubation. We included all adult (>18 years) medical and trauma patients undergoing rapid sequence intubation by emergency medicine residents or faculty.

We excluded cases in which there was failure of electronic vital sign data acquisition, inadequate nursing or physician documentation of the procedure, or a poor SpO_2 waveform during rapid sequence intubation, as well as those in which anesthesia providers managed the case.

Methods of Measurement

We determined rapid sequence intubation vital signs through a bedside continuous data acquisition system (BMEX data acquisition system; Excel Medical Electronics, Jupiter, FL). This software prospectively records all vital

sign data appearing on bedside cardiac monitors (General Electric Solar 8000i; General Electric Company, Fairfield, CT). We configured BMEX to record continuous waveform data and discrete numeric data on pulse rate, blood pressure, and SpO_2 every 5 seconds.

We used nursing documentation to determine the start and completion times of rapid sequence intubation. We defined rapid sequence intubation start time as the time of paralytic administration and completion time as the time of endotracheal tube placement confirmation, usually by a combination of end tidal CO_2 detection, auscultation, and other clinical indicators of correct tube placement. We extracted physiologic data (continuous pulse rate, oxygen saturation, and blood pressure) from BMEX from 5 minutes before rapid sequence intubation start until 5 minutes after its completion.

We used the medical record to determine the number of intubation attempts, age, sex, intubator and intubator's level of training, induction agent, paralytic agent, device and technique used, and diagnosis. An intubation "attempt" was defined as a single insertion of the laryngoscope. A single reviewer, trained in abstraction, performed an initial blinded chart review, using a structured abstraction form. A second reviewer, blinded to desaturation events, independently reviewed 25% of cases for agreement on intubation start and stop times. Discordance was resolved by a third reviewer. Because intubation times were continuous variables, we used the intraclass correlation coefficient to assess interrater agreement.

Outcome Measures

The primary outcome was peri-intubation oxygen desaturation. We defined desaturation as a reduction in SpO_2 to less than 90% if the starting SpO_2 was greater than or equal to 90%, or a further reduction in SpO_2 for patients that began below 90%. Preoxygenation SpO_2 was defined as the mean of the SpO_2 values 1 minute before the start of rapid sequence intubation. The SpO_2 nadir during intubation was the lowest SpO_2 value recorded from the time of paralytic administration until tube confirmation.

Primary Data Analysis

Data were imported into and analyzed with Microsoft Excel (version 2013; Microsoft, Redmond, WA) and PASW Statistics for Windows (version 21.0; SPSS, Inc., Chicago, IL). Desaturation data were imported directly into Microsoft Excel, and using intubation start and completion times from the medical record, we calculated the SpO_2 nadir, length of desaturation, and change in SpO_2 during intubation.

We analyzed the data with descriptive statistics, determining the proportion of rapid sequence intubation cases with oxygen desaturation. Medians were compared with a Mann-Whitney *U* test. To identify optimal cut points for dichotomizing preintubation SpO_2 and intubation time, we constructed a receiver operating characteristic curve, identifying optimal cutoff values with the Youden J index.[19-21]

To identify factors associated with rapid sequence intubation oxygen desaturation, we fit a multivariable logistic regression model with oxygen desaturation as the dependent variable. In developing the multivariable model, we sought to balance conceptually important variables and available statistical power because we anticipated observing only a modest number of events. Therefore, our a priori analytic plan was to include preintubation SpO_2 less than 93%, number of intubation attempts, and intubation time as the primary variables in the model. We also planned to adjust for age and sex. If there were an adequate number of desaturation events ($\geq$60) to maintain a 1:10 ratio of variables to outcomes, we planned to fit a second model with additional adjustment for intubator, training level of the intubator, induction agent, diagnosis, and intubation method. We verified goodness of fit of the model with the Hosmer-Lemeshow test.

RESULTS

Characteristics of Study Subjects

During the 10-month study period, 265 patients underwent rapid sequence intubation in the ED; 99 patients were excluded, leaving 166 cases for analysis (Figure 1). The study group was 73% men, with a median age of 51 years (range 18 to 95 years). Underlying conditions included medical emergencies (sepsis, respiratory cause, altered mental status, etc 62%), neurologic emergencies (cerebrovascular accident and intracranial hemorrhage 17%), trauma (excluding intracranial hemorrhage 18%), and resuscitated cardiac arrest (3%) (Table 1). Table 2 shows that in a univariate analysis for the continuous variables, only age did not show a significant difference between groups.

Main Results

Of the 166 rapid sequence intubation cases included in the study, oxygen desaturation occurred in 59 (35.5%; 95% confidence interval [CI] 26% to 45%). The median oxygen desaturation was 80 seconds (interquartile range [IQR] 40, 155 seconds) (Figure 2). The change in SpO_2 between the start and end of intubation ranged from 15.5 to –58, with a median of –2.2 (–9.9 to –0.1) (Figure 3).

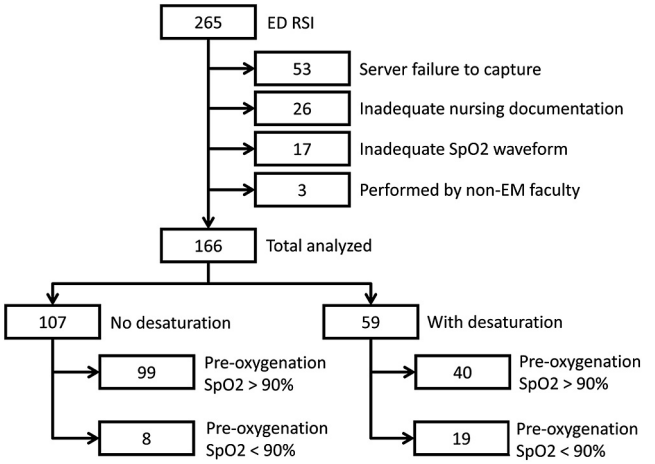

Figure 1. Breakdown of ED rapid sequence intubation cases during the 10-month period. *ED*, Emergency department; *RSI*, rapid sequence intubation; *EM*, emergency medicine.

Two investigators independently identified intubation times for 42 of the 166 rapid sequence intubation cases. Interrater agreement was strong (intraclass correlation coefficient=1.0, exact agreement in 95%).

Among the 166 rapid sequence intubation cases, 124 (75%) were successfully preoxygenated to an SpO_2 greater than 93%; for these cases, the median nadir SpO_2 during intubation was 95% (IQR 88%, 98%). The remaining 42 cases exhibited start SpO_2 less than 93%; the median nadir SpO_2 was 84% (IQR 70%, 89%). The percentile rank difference between these medians was 32% (95% CI 23% to 41%).

First-pass success occurred in 75% of rapid sequence intubation attempts; 16% of providers required 2 attempts, 6% required 3 attempts, and 3% required more than 3 intubation attempts. Nadir SpO_2 was higher for individuals with first-pass success than those requiring more than 1 attempt; median SpO_2 was 93% (IQR 87%, 98%) versus 85% (IQR 71%, 89%), respectively. The percentile rank difference between these medians was 18% (95% CI 8% to 28%).

Of the 3 unsuccessful rapid sequence intubation procedures, rescue airway measures included surgical airway (1 case) and fiber-optic intubation by anesthesia (2 cases). Peri-intubation cardiac arrest occurred in 4 patients (2.4%), with return of spontaneous circulation (ROSC) achieved in all 4 of these patients. Additional complications (eg, oral trauma, aspiration) were not reported.

Receiver operating characteristic curves indicated optimal cutoffs of 93% for dichotomizing SpO_2 and 3 minutes for dichotomizing intubation time. On multivariable logistic regression, preintubation SpO_2 less than 93%, intubation time greater than 3 minutes, or greater than 1 intubation attempt was independently associated with oxygen desaturation (Table 3). Hosmer-Lemeshow statistic indicated a good fit (P=.91). We did not observe an adequate number of desaturation events to adjust for additional variables in the model.

Table 1. Characteristics of ED rapid sequence intubation.*

Parameter	No Desaturation (n=107)	Desaturation (n=59)	Total (All Cases) (n=166)
Female sex	29 (27)	16 (27)	45 (27)
Induction agent			
Etomidate	31 (29)	19 (32)	50 (30)
Ketamine	31 (29)	19 (32)	50 (30)
Versed	27 (25)	14 (24)	41 (25)
Propofol	11 (10)	4 (7)	15 (9)
Ativan	2 (2)	1 (2)	3 (2)
None	5 (5)	2 (3)	7 (4)
Paralytic agent			
Rocuronium	95 (89)	54 (92)	149 (90)
Succinylcholine	11 (10)	3 (5)	14 (8)
Vecuronium	1 (1)	2 (3)	3 (2)
Level of intubator			
PGY1	9 (8)	6 (10)	15 (9)
PGY2	54 (50)	30 (51)	84 (51)
PGY3	42 (39)	22 (37)	64 (38)
Attending	2 (2)	1 (2)	3 (2)
Diagnosis			
Medical	66 (62)	41 (70)	107 (65)
Trauma†	24 (22)	6 (10)	30 (18)
Neurologic	17 (16)	12 (20)	29 (17)
Intubation method			
Direct	71 (66)	37 (63)	108 (65)
Video	17 (16)	16 (27)	33 (20)
Fiber optic	0	2 (3)	2 (1)
Unknown	19 (18)	4 (7)	23 (14)
Attempts			
1	90 (84)	35 (59)	125 (75)
2	11 (10)	15 (25)	26 (16)
3	6 (6)	4 (7)	10 (6)
>3	0	5 (8)	5 (3)

PGY, Post graduate year.
*Value for nominal and ordinal variables is No. (%).
†Excludes neurologic causes.

The series included 31 independent intubators, each managing from 1 to 20 of the cases included in the analysis. There was no evidence of oxygen desaturation clustering within intubators (intracluster correlation=–0.03), and therefore we considered all intubations to be independent.

LIMITATIONS

This was a single institutional study, and the results may not generalize to other institutions, depending on practice patterns. Although the vital sign data were prospectively collected, the chart review portion of data collection (intubation start/finish times and number of intubation attempts) was retrospective and therefore subject to reporting bias and data abstraction errors. We minimized this latter effect by following a standardized protocol when

Table 2. Characteristics of the continuous variables, including medians, percentiles of the medians, and 95% CIs.

	No Desat Group (Median/IQR) (n=107)	Desat Group (Median/IQR) (n=59)	Percentile of the Median for No Desat Group	Percentile of the Median for Desat Group	Difference in Percentile of the Medians (95% CI)
Age, y	51 (36 to 62)	49 (40 to 67)	49	53	4 (−5 to 13)
Preintubation SpO_2, %	98 (95 to 100)	93 (88 to 98)	59	35	23 (15 to 32)
Intubation time (median/IQR), min	2 (1 to 3)	3 (2 to 6)	45	61	16 (8 to 25)
No. of attempts (median/IQR)	1 (1 to 1)	1 (1 to 2)	46	59	13 (6 to 19)

extracting data from the medical record. We also performed a 25% independent review focused on the start and stop times and found exact agreement in 95% of cases.

Practice patterns in our ED at the study indicate that most patients received oxygenation by nonrebreather mask, with greater than or equal to 15 L of oxygen per minute or bag-valve-mask ventilation with supplemental oxygen and did not receive apneic (passive) nasal oxygenation; however, a detailed comparison of preoxygenation methods was not possible from our chart review. Additionally, preoxygenation was defined as the average SpO_2 during a minute preceding paralytics; it is possible that this value was lower than the actual value at rapid sequence intubation.

Finally, we were able to analyze only 63% of the possible intubations that occurred during this study period. The majority of excluded intubations (53/99) were due to technical issues, such as server error, that occurred randomly. Inadequate nursing documentation was responsible for 26 of 99 excluded cases, and we suspect this occurred randomly as well. Inadequate SpO_2 waveforms resulted in another 17 exclusions; it is possible that some of these were sicker patients with poor peripheral perfusion who were at higher risk for desaturation, thus biasing our results toward less desaturation.

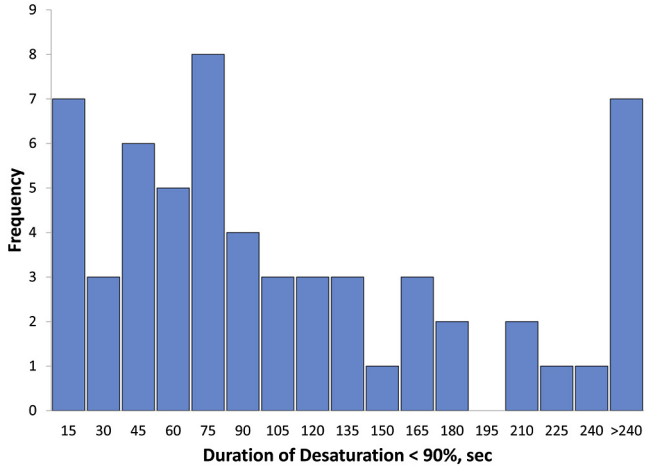

Figure 2. Duration of desaturation during RSI for patients who experienced desaturation (n=59). Oxygen desaturation was defined as SpO_2 less than 90% or reduction from preoxygenation baseline.

DISCUSSION

More accurate knowledge of the true rate of desaturations is critical to understanding patient risk during ED rapid sequence intubation and adjusting methods to avert this risk and its potentially serious complications. In this series, oxygen desaturation occurred in more than 1 of 3 ED rapid sequence intubation cases. Previous studies reported lower incidences of oxygen desaturation during emergency intubation, but with a wide range, from 0.2% to 19.2%.[9,11-15] These previous studies used manual recording of self-reported data, which is potentially subject to reporting bias.[9-16] In contrast, we used electronic data acquisition to obtain continuous physiologic data throughout the entire rapid sequence intubation procedure. The frequency of computer data capture (every 5 seconds) enabled us to identify oxygen desaturations episodes that may have been missed with manual recording. Our experience is similar to that of Dunford et al,[17] who used recording oximeter-capnometers to identify oxygen desaturation and reactive bradycardia during out-of-hospital rapid sequence intubation.

Most textbooks recommend preoxygenation for at least 3 minutes but do not provide a specific physiologic goal. We were unable to achieve preoxygenation SpO_2 levels greater than 93% in 25% of rapid sequence intubation

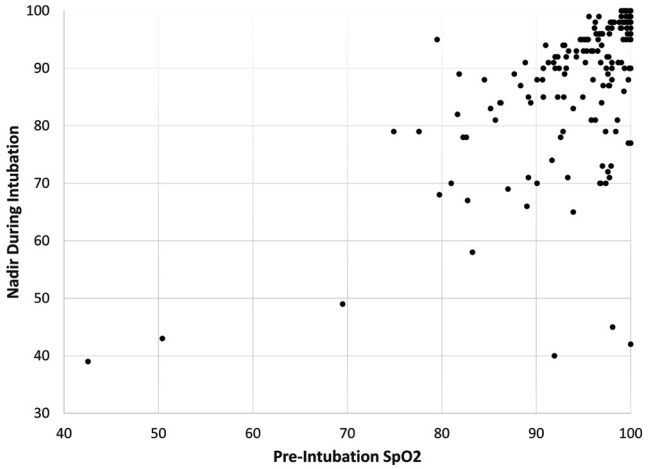

Figure 3. Change in SpO_2 during intubation (n=166).

Table 3. Multivariable analysis for the outcome of desaturation to less than 90%.*

Variable	AOR	Lower 95% CI on AOR	Upper 95% CI on AOR
Age	1.0	0.98	1.03
Female sex	0.9	0.4	2.1
Preintubation SpO_2 ≤93%	5.1	2.3	11.0
Intubation time >3 min	2.7	1.2	6.1
>1 attempt	3.4	1.4	8.2

AOR, Adjusted odds ratio.
*Model included 5 variables considered for the regression according to 59 desaturation outcomes. Hosmer-Lemeshow goodness-of-fit statistic *P*=.91.

attempts, and oxygen desaturation was 6 times more likely in these cases. This finding is consistent with work by Davis et al,[22] which demonstrated an inflection point at SpO_2 of 93% during out-of-hospital rapid sequence intubation; desaturation rates were much higher when SpO_2 was below this inflection point before the onset of rapid sequence intubation. These observations suggest that the goal for preoxygenation should be at least SpO_2 greater than 93%.

Pulmonary oxygen reserve is necessary to allow safe apnea time without desaturation.[1] The time to critical desaturation reflects the interplay between oxygen reserve and demand. Although we were unable to control for varying oxygen demand between patients, the inability to elevate saturation above 93% proved to be an independent clinical predictor of desaturation. However, even with preoxygenation to levels above 93%, several patients experienced profound desaturations. In one case, the initial SpO_2 was 100%, yet the patient's nadir SpO_2 was 42% with a 3-minute intubation procedure time, reinforcing that other factors such as oxygen demand play an important role in determining safe apnea time during rapid sequence intubation.

Expert opinion recommends limiting the number of intubation attempts.[23-25] Our observations reinforce the importance of first-pass success for patient safety during ED rapid sequence intubation because desaturation was 3 times more likely to occur with multiple intubation attempts. Although Sakles et al[26] used a 10% decline in SpO_2 to define desaturation, their data showed similar results, with a 9.8% incidence of desaturation with 1 intubation attempt and a 37.8% incidence when more than 1 attempt was needed.

We also found that desaturation was 3 times more likely to occur when intubation procedure times exceed 3 minutes. This observation highlights that the total intubation procedure time is as important as the number of laryngoscopy attempts. While trying to achieve first-pass success, clinicians should not necessarily extend the duration of the attempt. Our results do not indicate whether the risks of the number or total duration of attempts are mutually exclusive. For example, we do not know whether hypoxemia risk is greater with multiple short attempts versus a single prolonged laryngoscopy attempt.

To our knowledge, there is only 1 outcome study on the risks of desaturation during rapid sequence intubation. This study in severely head-injured patients demonstrated that profound desaturation during rapid sequence intubation resulted in higher mortality.[2] We also know that desaturation contributes to hemodynamic instability and eventually cardiac arrest.[3] Hypoxemia may then act as an important early proxy measure for adverse outcomes during rapid sequence intubation. Until more outcome data are available, achieving and maintaining an SpO_2 as high as possible during ED rapid sequence intubation makes good clinical sense. Strategies that have been demonstrated to improve preoxygenation and prolong safe apnea time include head-up positioning, noninvasive positive-pressure ventilation, apneic nasal oxygenation with regular or high flows, and delayed sequence intubation.[6,27-31] Another proposed approach to the hypoxemic patient is rapid sequence airway.[32] Emergency clinicians should consider incorporating all or some of these strategies in their rapid sequence intubation procedures.

In summary, 1 in 3 patients undergoing ED rapid sequence intubation experienced oxygen desaturation for a median duration of 80 seconds. Preintubation saturation less than 93%, multiple intubation attempts, and prolonged intubation time are independently associated with oxygen desaturation. Clinicians should use strategies to avoid oxygen desaturation during ED rapid sequence intubation.

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REFERENCES

1. Weingart SD, Levitan RM. Preoxygenation and prevention of desaturation during emergency airway management. *Ann Emerg Med*. 2012;59:165-175.
2. Davis DP, Dunford JV, Poste JC, et al. The impact of hypoxia and hyperventilation on outcome after paramedic rapid sequence intubation of severely head-injured patients. *J Trauma*. 2004;57:1-8.
3. Mort TC. The incidence and risk factors for cardiac arrest during emergency tracheal intubation: a justification for incorporating the ASA guidelines in the remote location. *J Clin Anesth*. 2004;16: 508-516.
4. Heffner AC, Swords DS, Neale MN, et al. Incidence and factors associated with cardiac arrest complicating emergency airway management. *Resuscitation*. 2013;84:1500-1504.
5. Schwartz DE, Matthay MA, Cohen NH. Death and other complications of emergency airway management in critically ill adults. A prospective investigation of 297 tracheal intubations. *Anesthesiology*. 1995;82:367-376.
6. Weingart SD. Preoxygenation, reoxygenation, and delayed sequence intubation in the emergency department. *J Emerg Med*. 2011;40: 661-667.
7. Bratton SL, Chestnut RM, Ghajar J, et al. Guidelines for the management of severe traumatic brain injury. I. Blood pressure and oxygenation. *J Neurotrauma*. 2007;24(suppl 1):S7-13.
8. Mayglothling J, Duane TM, Gibbs M, et al. Emergency tracheal intubation immediately following traumatic injury: an Eastern Association for the Surgery of Trauma practice management guideline. *J Trauma Acute Care Surg*. 2012;73(5 suppl 4):S333-S340.
9. Tayal VS, Riggs RW, Marx JA, et al. Rapid-sequence intubation at an emergency medicine residency: success rate and adverse events during a two-year period. *Acad Emerg Med*. 1999;6:31-37.
10. Li J, Murphy-Lavoie H, Bugas C, et al. Complications of emergency intubation with and without paralysis. *Am J Emerg Med*. 1999;17:141-143.
11. Sakles JC, Mosier JM, Chiu S, et al. Tracheal intubation in the emergency department: a comparison of GlideScope(R) video laryngoscopy to direct laryngoscopy in 822 intubations. *J Emerg Med*. 2012;42:400-405.
12. Sakles JC, Laurin EG, Rantapaa AA, et al. Airway management in the emergency department: a one-year study of 610 tracheal intubations. *Ann Emerg Med*. 1998;31:325-332.
13. Reid C, Chan L, Tweeddale M. The who, where, and what of rapid sequence intubation: prospective observational study of emergency RSI outside the operating theatre. *Emerg Med J*. 2004;21:296-301.
14. Omert L, Yeaney W, Mizikowski S, et al. Role of the emergency medicine physician in airway management of the trauma patient. *J Trauma*. 2001;51:1065-1068.
15. 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;60:749-754.
16. Varga S, Shupp JW, Maher D, et al. Trauma airway management: transition from anesthesia to emergency medicine. *J Emerg Med*. 2013;44:1190-1195.
17. Dunford JV, Davis DP, Ochs M, et al. Incidence of transient hypoxia and pulse rate reactivity during paramedic rapid sequence intubation. *Ann Emerg Med*. 2003;42:721-728.
18. Wimalasena Y, Burns B, Reid C, et al. Apneic oxygenation was associated with decreased desaturation rates during rapid sequence intubation by an Australian helicopter emergency medicine service. *Ann Emerg Med*. 2014.
19. Bohning D, Bohning W, Holling H. Revisiting Youden's index as a useful measure of the misclassification error in meta-analysis of diagnostic studies. *Stat Methods Med Res*. 2008;17:543-554.
20. Seymour CW, Cooke CR, Heckbert SR, et al. Prehospital systolic blood pressure thresholds: a community-based outcomes study. *Acad Emerg Med*. 2013;20:597-604.
21. Liu XW, Ma T, Qu B, et al. Prognostic value of initial arterial lactate level and lactate metabolic clearance rate in patients with acute paraquat poisoning. *Am J Emerg Med*. 2013;31:1230-1235.
22. Davis DP, Hwang JQ, Dunford JV. Rate of decline in oxygen saturation at various pulse oximetry values with prehospital rapid sequence intubation. *Prehosp Emerg Care*. 2008;12:46-51.
23. Levitan RM. *The Airway Cam Guide to Intubation and Practical Emergency Airway Management*. Wayne, PA: Airway Cam Technologies, Inc; 2004.
24. Braude D. *Rapid Sequence Intubation and Rapid Sequence Airway, 2nd Edition: An Airway911 Guide*. Albuquerque, NM: Department of Emergency Medicine; 2009.
25. Walls RM, Murphy MF. *Manual of Emergency Airway Management*. 4th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2012.
26. Sakles JC, Chiu S, Mosier JM, et al. The importance of first pass success when performing orotracheal intubation in the emergency department. *Acad Emerg Med*. 2013;20:71-78.
27. Dixon BJ, Dixon JB, Carden JR, et al. Preoxygenation is more effective in the 25 degrees head-up position than in the supine position in severely obese patients: a randomized controlled study. *Anesthesiology*. 2005;102:1110-1115.
28. Baillard C, Fosse JP, Sebbane M, et al. Noninvasive ventilation improves preoxygenation before intubation of hypoxic patients. *Am J Respir Crit Care Med*. 2006;174:171-177.
29. Ramkumar V, Umesh G, Philip FA. Preoxygenation with 20 masculine head-up tilt provides longer duration of non-hypoxic apnea than conventional preoxygenation in non-obese healthy adults. *J Anesth*. 2011;25:189-194.
30. Weingart SD, Trueger NS, Wong N, et al. Delayed sequence intubation: a prospective observational study. *Ann Emerg Med*. 2014.
31. Miguel-Montanes R, Hajage D, Messika J, et al. Use of high-flow nasal cannula oxygen therapy to prevent desaturation during tracheal intubation of intensive care patients with mild-to-moderate hypoxemia. *Crit Care Med*. 2015;43:574-583.
32. Braude D, Southard A, Swenson K, et al. Using rapid sequence airway to facilitate preoxygenation and gastric decompression prior to emergent intubation. *J Anesth Clin Res*. 2010;01:113.