Use of End Tidal Oxygen Monitoring to Assess Preoxygenation During Rapid Sequence Intubation in the Emergency Department

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Study objective: Preoxygenation is important to prevent oxygen desaturation during emergency airway management. The purpose of this study is to describe the use of end tidal oxygen (ETO_2) during rapid sequence intubation in the emergency department.

Methods: This study was carried out in 2 academic centers in Sydney, Australia, and New York City. We included patients undergoing rapid sequence intubation in the emergency department. A standard gas analyzer was used to measure ETO_2. Preoxygenation methods included nonrebreather mask and bag-valve-mask ventilation. We measured ETO_2 before preoxygenation and at administration of rapid sequence intubation medications. We also characterized peri-intubation SpO_2, identifying instances of SpO_2 less than 90%.

Results: We included 100 patients during a 6-month period. Median ETO_2 level before and after preoxygenation was 53% (interquartile range [IQR] 43% to 65%) and 78% (IQR 64% to 86%), respectively. One fourth of patients achieved an ETO_2 level greater than 85%. Median ETO_2 level achieved varied with preoxygenation method, ranging from 80% (IQR 60% to 87%) for the nonrebreather mask group to 77% (IQR 65% to 86%) for the bag-valve-mask group. The method with the highest median ETO_2 level was nonrebreather mask at flush rate (86%; IQR 80% to 90%) and the lowest median ETO_2 level was nonrebreather mask at 15 L/min (57%; IQR 53% to 60%). Eighteen patients (18%) experienced oxygen desaturation (SpO_2 <90%); of these, 14 (78%) did not reach an ETO_2 level greater than 85% at induction.

Conclusion: ETO_2 varied with different preoxygenation techniques employed in the emergency department. Most patients undergoing rapid sequence intubation did not achieve maximal preoxygenation. Measuring ETO_2 in the emergency department may be a valuable adjunct for optimizing preoxygenation during emergency airway management. [Ann Emerg Med. 2019;■:1-6.]

Please see page XX for the Editor's Capsule Summary of this article.

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INTRODUCTION

Background

Rapid sequence intubation is the most common method of airway management in the emergency department (ED).[1] Use of an induction agent and a neuromuscular-blocking agent results in transient apnea during the intubation attempt. If prolonged, apnea and resulting oxygen desaturation may lead to serious adverse events such as dysrhythmias, hypotension, and cardiac arrest.[2] Although practice guidelines advocate preoxygenation to prevent oxygen desaturation, the adequacy of preoxygenation is not typically assessed in the ED.[3-5]

Importance

In the operating room, anesthesiologists have used gas analyzers to quantify and optimize preoxygenation.[6,7] The Difficult Airway Society suggests that when critically ill patients are intubated, preoxygenation should be performed until an ETO_2 level of greater than or equal to 85% is attained.[5,8] ETO_2 level has not been widely used in clinical practice in the ED.

Goals of This Investigation

We sought to describe our preliminary use of ETO_2 to assess preoxygenation during rapid sequence intubation in the ED.

Study Design and Setting

We conducted a prospective observational cohort study at 2 urban, academic EDs in Sydney, Australia, and New York City. This study was approved with waiver of consent by the institutional review board and ethics boards at each institution.

Editor's Capsule Summary

What is already known on this topic

Preoxygenation is recommended before rapid sequence intubation.

What question this study addressed

Can end tidal expired oxygen levels (ETO_2) characterize preoxygenation before rapid sequence intubation?

What this study adds to our knowledge

In this series of 100 rapid sequence intubations, median ETO_2 levels before and after preoxygenation were 53% (interquartile range 43% to 65%) and 78% (interquartile range 64% to 86%). Of the 18 patients experiencing oxygen desaturation (SaO_2 <90%), 14 (78%) had an ETO_2 level less than 85% before induction.

How this is relevant to clinical practice

ETO_2 level may be useful for guiding preoxygenation during rapid sequence intubation in the ED. However, formal validation is necessary before clinical implementation.

The annual census of each ED was 175,000 patients (New York) and 80,000 patients (Sydney). The departments perform greater than 900 intubations a year combined (approximately 300 at the Sydney site and 600 at the New York site). Each department has emergency medicine trainees. The majority of intubations are performed by emergency medicine trainees under the direct supervision of an emergency medicine attending physician. Both sites practice rapid sequence intubation, with the specific technique used chosen by the emergency medicine attending physician.

Clinical airway management practices at each site called for a minimum of 3 minutes of preoxygenation with either a bag-valve-mask device or a nonrebreather mask before rapid sequence intubation. If a bag-valve-mask device was used, the mask seal was maintained by the operator, and assisted breaths were given at the discretion of the attending physician. Positive end-expiratory pressure could be provided if clinically warranted by means of a positive end-expiratory pressure valve connected to the bag-valve-mask device, and at pressures ranging from 1 to 20 cm H_2O. For nonrebreather mask, the oxygen flow rate was selected by the emergency medicine attending physician and was set at either 15 L/min or flush rate (50 to 70 L/min at the New York site and 19 L/min at the Sydney site). The use of supplemental nasal cannula oxygen was chosen by the attending emergency physician and ranged from 15 L/min to flush rate.

Selection of Participants

We included all adult patients (≥18 years) undergoing rapid sequence intubation during October 2017 to February 2018. We excluded patients in cardiac arrest, receiving noninvasive ventilation before intubation, intubated in the out-of-hospital setting, or who underwent awake intubation.

Methods of Measurement

To quantify ETO_2 level achieved with current preoxygenation practices, emergency physicians were blinded to the ETO_2 data collected during the procedure. Independent observers (research assistants, nurses, and residents) collected all ETO_2 measurements. The observers underwent training for the study and collected data in real time, using a standardized data collection tool.

Vital signs were obtained from the cardiac monitor (Philips IntelliVue; Philips, Andover, MA) in real time. ETO_2 level was measured by Phillips G5 Gas Analyzer (Philips) at the New York site and by a Philips G7 Gas Analyzer (Philips) at the Sydney site. The newer-generation G7 module is a more compact version of the G5 and facilitates similar ETO_2 measurements. Although not the focus of this study, the devices also measured FiO_2. The analyzers use a single flow sensor to make measurements for FiO_2 supplied and ETO_2 exhaled by gas sampling. SpO_2 was measured through standard finger oximeters (Covidien Oximax; Covidien). Hypoxemia was defined as an SpO_2 level less than 90%.

For patients undergoing bag-valve-mask preoxygenation, ETO_2 level was measured by side-stream gas sampling connected between the bag-valve-mask device and the mask. For patients receiving nonrebreather mask preoxygenation, side-stream sampling was used by means of a nasal prong gas sampler (AirLife $ETCO_2$ Nasal Cannula at the New York site and CapnoEZY at the Sydney site). For patients receiving preoxygenation by nonrebreather mask plus nasal cannula oxygen, the New York site used a separate standard nasal cannula. The Sydney site used CapnoEZY nasal prongs. Waveform capnography was used to verify that ventilation was occurring during ETO_2 measurement recordings.

To validate the use of single-breath versus continuous ETO_2 measurements, we conducted a preliminary study using 4 healthy volunteers (attaining 20 measurements at each site). We compared continuous and single-breath ETO_2 measurements for both bag-valve-mask device and

nonrebreather mask (n=10 measurements for each method). Each volunteer was preoxygenated for 3 minutes with bag-valve-mask device and nonrebreather mask. The ETO_2 was recorded at the end of 3 minutes of continuous analysis. At the conclusion of the 3 minutes, the subject held a single breath for 10 seconds and then exhaled. This single-breath measurement was then compared with the final measurement during the continuous ETO_2 measurement.

Preoxygenation interval was defined as the elapsed time from emergency medicine attending physician decision to intubate to the point of induction. Apnea time was defined as the elapsed time from induction to confirmation of tube placement by waveform capnography. All other data on baseline characteristics, pre- and postlaryngoscopy management, and clinical outcomes were collected from the medical record by study personnel. We tested interrater agreement for ETO_2 and SpO_2 by using the first 5 cases.

Outcome Measures

The primary outcome was ETO_2 level, measured before preoxygenation and at induction. The secondary outcome was SpO_2, measured before and immediately after intubation.

Primary Data Analysis

To validate the use of single-breath versus continuous ETO_2 in healthy volunteers, we used Pearson's correlation coefficient and a Bland-Altman plot. For the clinical series, we analyzed the data with descriptive techniques. We determined median ETO_2 level before preoxygenation and at induction, and SpO_2 before and after intubation, examining the full cohort, as well as stratifying by preoxygenation technique. We plotted ETO_2 and SpO_2 measurements for each patient. We determined the proportion of patients achieving ETO_2 level greater than 85%. We also determined the proportion of patients who experienced oxygen desaturation (SpO_2 <90%). For the initial 5 subjects, we assessed percentage agreement between raters. All analyses were performed with XLStat (version 2018.7; Addinsoft, New York, NY).

RESULTS

In the validation of continuous versus single-breath ETO_2 measurements using human volunteers, continuous ETO_2 level for the bag-valve-mask group was 82% (95% confidence interval [CI] 80% to 86%) and single-breath ETO_2 was 80% (95% CI 74% to 86%); the mean difference was 2.2% (95% CI 1.4% to 3%) for the bag-valve-mask group. Continuous ETO_2 level for the nonrebreather mask group was 70% (95% CI 62% to 78%) for continuous ETO_2, and single-breath ETO_2 was 75% (95% CI 68% to 82%); the mean difference was 5% (95% CI 3.5% to 6.5%) for the nonrebreather mask group. Agreement was good between the measures with Pearson's correlation coefficient 0.81 (95% CI 0.59 to 0.92) for the bag-valve-mask device and 0.75 (95% CI 0.45 to 0.90) for nonrebreather mask (Bland-Altman plot depicted in Figure E1, available online at http://www.annemergmed.com).

Of 154 patients undergoing rapid sequence intubation, we included 100, including 75 at the New York site and 25 at the Sydney site. Reasons for exclusion included the following: noninvasive ventilation before intubation (n=18), intubation in the field (n=11), use of "awake" intubation (n=13), and traumatic cardiac arrest (n=3). Data were not available for 9 patients. The cohort was composed of older patients, greater than half of whom were men, with a primary indication for intubation that was pulmonary at the New York site and neurologic at the Sydney site (Table). Video laryngoscopy was used for 55% of patients at the New York site (data not collected at the Sydney site), and senior trainees intubated 65% of the patients. The first-pass success was 90% and all patients were intubated within 2 attempts.

For the first 5 consecutively included patients, interrater agreement was high for ETO_2 (percentage agreement=80%) and SpO_2 (percentage agreement=100%) before preoxygenation and at rapid sequence intubation induction.

The median ETO_2 level at initiation of preoxygenation was 53% (interquartile range [IQR] 43% to 65%) and at induction was 78% (IQR 64% to 86%). The median ETO_2 levels for the nonrebreather mask and the bag-valve-mask device subgroups were similar at induction (80%, IQR 59% to 87%; and 77%, IQR 65% to 86%, respectively). The method with the highest median ETO_2 level was nonrebreather mask at flush rate (86%; IQR 80% to 90%), and the lowest median ETO_2 level was nonrebreather mask at 15 L/min (57%; IQR 53% to 60%). The median FiO_2 at induction was 90% (IQR 78% to 94%). The mean SpO_2 at induction was 97% (95% CI 93% to 99%). Oxygen saturations were higher during rapid sequence intubation when higher ETO_2 levels were achieved by induction (Figure). Only approximately a quarter of the patients achieved an ETO_2 level greater than 85% (n=26). Of 100 patients, 36 (36%) were able to be preoxygenated to an ETO_2 level of 70% to 85%, and 27 (27%) to an ETO_2 level of 50% to 69%. A total of 11 patients (11%) did not achieve an ETO_2 level greater than 50%; the majority were in the bag-valve-mask group.

Table. Baseline characteristics of the overall cohort.

Characteristic	Site 1 (n=75)	Site 2 (n=25)	Total Cohort (N=100)
Age, median (IQR), y	57	41	53
Male sex, No. (%)	50	60	56
Indication, No. (%)			
Pulmonary	36	1	37 (37)
Neurologic	18	7	25 (25)
Trauma	14	5	19 (19)
Infections (not including pulmonary)	1	6	7 (7)
Other	6	6	12 (12)
Preoxygenation method, No. (%)			
BVM at 15 L/min	7	6	12 (12)
BVM at FR	17	0	17 (17)
BVM+PEEP at 15 L/min	4	8	13 (13)
BVM+PEEP at FR	13	0	13 (13)
NRB at 15 L/min	9	3	12 (12)
NRB at FR	17	0	17 (17)
NRB+NC at 15 L/min	4	8	12 (12)
NRB+NC at FR	4	0	4 (4)
Timing			
Preoxygenation time, median (IQR), min	12 (11 to 15)	11 (8 to 14)	12 (10 to14)
Operator level of training, No. (%)			
PGY			
1	11	0	8
2	36	0	27
≥3	53	100	65

BVM, Bag-valve-mask; *PEEP*, positive end-expiratory pressure; *NRB*, nonrebreather mask; *FR*, flush rate (ie, 50 to 70 L/min); *NC*, nasal cannula; *PGY*, postgraduate year.

A total of 18 patients (18%) desaturated below 90%, and 2 (2%) desaturated below 80%. Of these 18 patients, 2 (11%) had an ETO_2 level greater than 85% at rapid sequence intubation induction; the remaining cases had ETO_2 level less than 85% at induction.

LIMITATIONS

There are several limitations to this study. The study centers were academic EDs with training programs, and thus the results may not generalize to nonacademic centers. Because of the preliminary nature of this study, we did not compare differing techniques nor associations with patient outcomes or adverse events (dysrhythmia, hypotension, and cardiac arrest). Although this was a limitation, we believed it was necessary to determine the foundation of whether an issue existed with current preoxygenation strategies or techniques in the ED by means of measuring ETO_2. Although our validation of continuous monitoring demonstrated results similar to those of a single breath technique, they were not identical, so caution needs to be taken. The type of monitoring technique may have limitations on accuracy because there is a potential for a difference between single-breath and continuous ETO_2 measurements. The ETO_2 results of continuous measuring may be slightly higher than single-breath measurements in critically ill patients because of oxygen mixing from the source in the mask when the patient is not ventilating adequately, which does not occur during a single-breath measurement. In critically ill patients, it is difficult to control for tidal volume breathing before securing an airway, and therefore mixing may take place at times.

ETO_2 represents only a measure of the concentration of oxygen in the functional reserve capacity. Critically ill patients may achieve a very high ETO_2 but have a short safe apnea time because of a markedly reduced functional reserve capacity, increased oxygen consumption, or both.[9] ETO_2 measurements can be inaccurate if proper technique is not used. For example, in a patient with severe hypoventilation the oxygen analyzer would essentially measure the FiO_2 being delivered to the patient.[10] The concurrent use of waveform analysis (of both carbon dioxide and oxygen) is vital to determine alveolar gas exchange.

Although our gas analyzer devices were able to measure FiO_2, we limited inferences on this measure because of inherent technical limitations with this technique; for example, if a patient receiving nonrebreather mask is not ventilating well, the supplemental oxygen may concentrate in the mask, causing falsely elevated FiO_2. If validated, measured FiO_2 could offer another tool for monitoring and enhancing preoxygenation.

DISCUSSION

In this observational study, we describe our experience with using ETO_2 as a means of quantifying the adequacy of current preoxygenation strategies in the ED. ETO_2 use must be formally validated before its widespread use in the ED setting. However, this technology could provide an additional tool to guide clinical care during emergency airway management.

Denitrogenation of the functional reserve capacity with oxygen is a vital step in preoxygenation before intubation to create an intrapulmonary reservoir of oxygen that prevents hypoxemia during the apneic phase of intubation. Gas analysis monitoring of ETO_2 results has been used in the operating room for decades to help guide clinicians on the

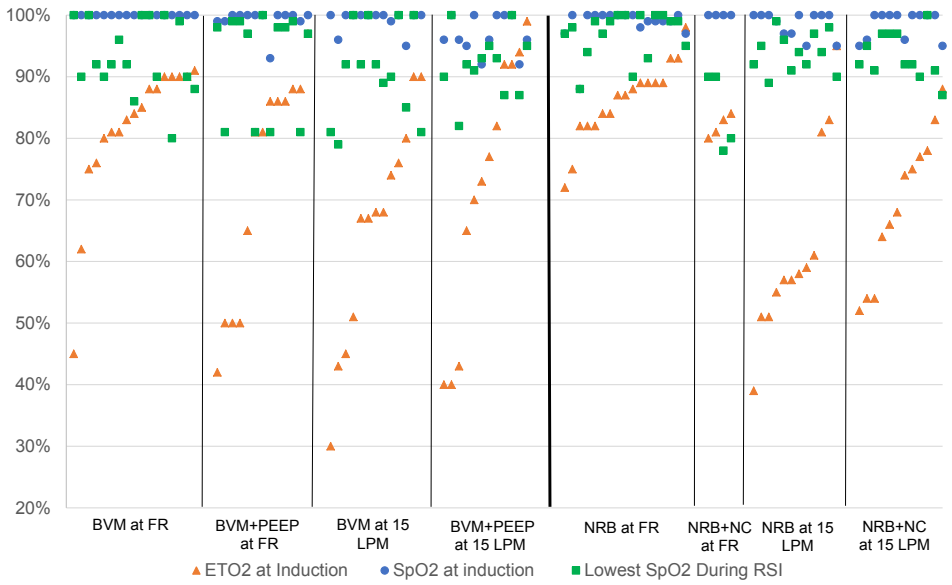

Figure. Induction ETO_2, induction SpO_2, and lowest SpO_2 measurement for each rapid sequence intubation patient. LPM, Liters per minute; RSI, rapid sequence intubation.

effectiveness of denitrogenation before a patient undergoes anesthesia for operative intervention.[10,11] These analyzers provide useful information that can be used to adjust in real time the method of preoxygenation being used, adjust what flow rate is being used, determine whether there is good mask seal, and determine whether these adjustments make a difference. Historically, EDs have not routinely used gas analyzers for ETO_2, likely because of the lack of access to the technology, high costs, and unfamiliarity with the device and technique. Although rapid sequence intubation in the ED includes the preoxygenation phase of patients, because the procedure is generally considered to be deemed emergency, this may reflect less than adequate focus being placed on spending time and resources on optimizing patients, who are already at high risk for desaturation by the nature of their critical illness.[3] Many articles in the emergency medicine literature have emphasized the importance of the preoxygenation of patients, and subsequently clinical practices have changed to optimize patients before intubation.[3,12] This is where the implementation of ETO_2 may have use.

We found that only 26% of patients were able to be preoxygenated to the recommended goal of an ETO_2 level greater than or equal to 85%.[5,8] There are a number of potential causes for low ETO_2 measurements. Low FiO_2 may result from inadequate oxygen flow or leaks in the face mask seal. Also, the time required for denitrogenation varies between patients; 3 minutes may not be sufficient for some patients. In the operating room, Baillard et al[13] found that of 1,050 patients preoxygenated for a set time of 3 minutes with an anesthetic circuit, only 44% achieved adequate preoxygenation, defined as ETO_2 level greater than or equal to 90%. Given that this study was conducted in the controlled environment of the operating room on elective surgical patients, it perhaps is not surprising that the majority of patients who achieved optimal preoxygenation in our study was so low. Compared with studies on healthy volunteers undergoing preoxygenation, our results appear to be fairly similar.[14-17] This suggests that measuring ETO_2 in critically ill patients is feasible and may be useful to help optimize preoxygenation.

In summary, in this preliminary study we observed considerable variation in ETO_2 level during preoxygenation for ED rapid sequence intubation. ETO_2 may be a useful adjunct to optimize preoxygenation during emergency airway management.

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