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ORIGINAL RESEARCH

Airway

Emergency physician use of end-tidal oxygen monitoring for rapidsequence intubation

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Abstract

Background: End-tidal oxygen (ETO_2) monitoring is used by anesthesiologists to quantify the efficacy of preoxygenation before intubation but is generally not used in emergency departments (EDs). We have previously published our findings describing preoxygenation practices in the ED during blinded use of ETO_2. The purpose of this investigation is to determine whether the unblinded use of ETO_2 monitoring led to improvements in preoxygenation during rapid sequence intubation in the ED and also the oxygen device or technique changes that were used to achieve higher ETO_2 levels.

Methods: We conducted an interventional study at 2 academic EDs in Sydney, Australia and New York City, New York using ETO_2 monitoring to investigate the preoxygenation process and effectiveness. We used data collected during a previous descriptive study for the control group, in which care teams in the same 2 EDs were blinded to the ETO_2 value. In the study group, clinicians could utilize ETO_2 to improve preoxygenation. Following an education process, clinicians were able to choose the method of preoxygenation and the techniques required to attempt to achieve an ETO_2 level >85%. The primary outcome was the difference in ETO_2 levels at the time of induction between the control and study group and the secondary outcome included the methods that were attempted to improve preoxygenation.

Results: A convenience sample of 100 patients was enrolled in each group. The median ETO_2 level achieved at the time of induction was 80% (interquartile range 61 to 86, overall range 73) in the control group and 90% in the study group (interquartile range 83 to 92, overall range 41); the median difference was 12 (95% confidence interval: 8, 16, $P = < 0.001$). The majority of oxygen device changes were from non-rebreather

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mask to bag-valve-mask (BVM) (15%, n = 15) and changes in technique from improvements in mask seal (54%, n = 34). The final device used in the study group was BVM in 87% of cases.

Conclusions: In 2 clinical studies of ETO_2 in academic EDs, we have demonstrated that the use of ETO_2 is feasible and associated with specific and potentially improved approaches to preoxygenation. A clinical trial is needed to further study the impact of ETO_2 on the preoxygenation process and the rate of hypoxemia.

KEYWORDS
Airway, Emergency, Intubation, Preoxygenation, Resuscitation

1 | INTRODUCTION

1.1 | Background

Patients undergoing rapid sequence intubation (RSI) in the emergency department are at risk of adverse events, with previous literature indicating that adverse events occur in as many as 1 in 4 patients.[1,2] Hypoxemia is common during emergency intubation and one of the main risk factors for more severe adverse events.[3–8] Preoxygenation creates a reservoir of oxygen in the alveoli and tissues that can help maintain adequate hemoglobin saturation during the apneic period of RSI and therefore help minimize the risk of hypoxemia and its associated complications.

1.2 | Importance

Currently, standard preoxygenation in the ED involves either the delivery of a high concentration of oxygen via a non-rebreather mask (NRB) or bag-valve-mask (BVM) with the aim of maximally denitrogenating the lungs thereby creating a large intrapulmonary reservoir of oxygen. Unfortunately, there is no routine objective measurement of the efficacy of preoxygenation in the ED, so clinicians rely on oxygen saturations (SpO_2) and delivering oxygen for a defined period of time, most commonly 3 minutes. The reliance on 3 or more minutes is based on a study performed in 1983 on 12 healthy volunteers and 20 elective surgery patients and therefore the applicability to patients undergoing RSI in the ED is unclear.[9] The only objective measure of preoxygenation in the ED is to use SpO_2; however, this is an indirect measurement of preoxygenation as SpO_2 levels do not give any information on the level of denitrogenation.

End-tidal oxygen (ETO_2) monitoring is routinely used by anesthesiologists before intubation in the operating room (OR) to objectively measure the efficacy of the denitrogenation process. In critically ill patients, a goal of an ETO_2 level of >85% is recommended and indicates maximal denitrogenation of the functional reserve capacity (FRC).[10] The aim of achieving higher ETO_2 levels is to create the largest possible reservoir of oxygen in the FRC to help maintain hemoglobin saturation during the apneic phase of RSI.

We recently published a study of preoxygenation practices using ETO_2 monitoring in the ED.[11] By blinding clinicians to the ETO_2 results and measuring the levels during the preoxygenation period we demonstrated that the vast majority of patients had suboptimal preoxygenation. Only 26% of patients reached the recommended target of >85% and alarmingly 11% of patients were preoxygenated to levels of < 50%.

Currently, ETO_2 monitoring is not typically performed in EDs and so adequacy of preoxygenation before RSI is unknown. Before the introduction of this technology in EDs, it is important to evaluate whether real-time ETO_2 monitoring would provide any improvements in preoxygenation measured by ETO_2 levels. If current clinical practices demonstrate adequate ETO_2 levels without ETO_2 monitoring, then the implementation of the technology may not be necessary.

1.3 | Goals of this investigation

We hypothesized that preoxygenation in the ED, measured by ETO_2 levels at induction, is often inadequate and that unblinding ETO_2 monitoring to clinicians alters preoxygenation practices that could improve preoxygenation (ETO_2 at induction). To investigate this, we conducted a study to evaluate preoxygenation in the ED with the use of ETO_2 monitoring and the strategies that were implemented by clinicians to achieve improvements in preoxygenation with the use of ETO_2 monitoring.

2 | METHODS

2.1 | Study design and setting

We conducted a prospective, interventional study with convenience sampling of patients at 2 urban, high volume, academic EDs in Sydney, Australia and New York City, New York. We used data from our previously published paper as the control group where clinicians were blinded to ETO_2 results during the preoxygenation process. In the study group, clinicians were able to visualize the ETO_2 result and alter preoxygenation strategies and techniques with the aim to achieve an ETO_2 value of >85% prior to the administration of the induction agent and paralytic agent.

This study was approved with waiver of consent of patients by the institutional review board and ethics board at each institution. A previously published paper by the authors describes the specifics of the departmental settings and clinical management of patients during RSI in the ED.[11] Practices of RSI are very similar at each institution. However, flush rate oxygen delivery was achieved only at the NYC site at ≈50–70 L/min; the Sydney site did not have access to flush rate oxygen. Also, there is a difference in the level of training of the operators, with trainees of all levels performing the intubations at the NYC site and only senior-level residents performing the intubations at the Sydney site.

The Bottom Line

Standard approaches to assess the adequacy of preoxygenation before rapid sequence intubation have significant limitations. This before-and-after study of adult patients in 2 emergency departments suggests end-tidal oxygen measurement may significantly improve the adequacy of preoxygenation and the safety of rapid sequence intubation. End-tidal oxygen measurement to assess preoxygenation warrants additional investigation.

2.2 | Selection of participants

Any adult patient (≥18 years) undergoing RSI in the ED was considered for inclusion in the study. Patients who were not considered suitable for the study included those in cardiac arrest, patients who received non-invasive ventilation before intubation, and those who underwent awake intubation.

2.3 | Intervention

Before the commencement of the study, ETO_2 monitors were installed in resuscitation bays at both institutions. Following the completion of data collection for the control group, staff at both sites underwent the same educational intervention describing the role of ETO_2 monitoring. During these education sessions staff received education related to how ETO_2 monitoring works including the ideal ETO_2 level to be achieved of >85%. A brief discussion was conducted during these education sessions on the available options to physicians that may affect the ETO_2 level. These options included techniques or oxygen devices that are of common knowledge and routinely used in clinical practice by physicians to improve oxygenation in EDs. These techniques included: improvement of mask seal, increased oxygen flow rate, and/or increased preoxygenation time. The oxygen device options included: addition of conventional nasal cannula oxygen, a change to NRB, a change to BVM, or a change to BVM with a positive end expiratory pressure (PEEP) valve. Physicians were informed of these options during the education session and allowed to choose any of these options if the ETO_2 value was ≤85% with these modifications recorded on the data collection sheet; however, alterations using these modifications were not mandatory if the ETO_2 was ≤85%. Physicians were not informed of any specific preoxygenation technique or oxygen device that could lead to improvements in ETO_2 levels above any other technique or device.

Given the clinical urgency of RSI in the ED, we recommended to physicians that if it was not possible to achieve an ETO_2 of >85% after 3 minutes of the highest recorded ETO_2, even after an intervention described previously, then they were advised to proceed with intubation. This was to prevent physicians attempting multiple different methods that may subsequently cause a delay to patients receiving a definitive airway.

2.4 | Methods of measurement

A full methodology has been outlined in a previous paper.[11] In brief, ETO_2 monitoring commenced at the start of preoxygenation, that is, at the decision for RSI and continued until successful tracheal intubation was achieved. For patients preoxygenated with a BVM, a sidestream gas sampling line was connected between the bag and the mask of the device. For patients preoxygenated with a NRB, nasal prongs were used to sample gas for analysis. ETO_2 levels were measured by Phillips G5 Gas Analyzer (Philips) at the NYC site and by a Philips G7 Gas Analyzer (Philips) at the Sydney site. Data were recorded during the RSI by observers independent of the clinical team on data collection sheets. ETO_2 values were recorded at the initiation of preoxygenation, at induction, and at the first exhalation following tracheal intubation. The techniques that were used to improve the preoxygenation (listed in "intervention") were also recorded on the data collection sheet by the observers. To ensure the accuracy of the data collected, waveform capnography tracings were recorded and classified as good (rectangular), poor (non-rectangular), or absent (flat).

2.5 | Outcomes measures

The primary outcome for the study was to determine the effect of unblinded use (study group) of ETO_2 monitoring on the median difference in ETO_2 levels achieved at the time of induction compared to the blinded (control group) use of ETO_2. ETO_2 levels were also stratified into the following groups for comparison: >85%, 70%–85%, 50%–69%, and < 50%. The secondary outcomes included the changes in preoxygenation techniques that clinicians employed to optimize ETO_2. Also, the prevalence of hypoxemia, defined as SpO_2 <90% recorded during the peri-intubation period of up to 2 minutes post-intubation, was compared between the control and study group.

2.6 | Primary data analysis

Medians and proportions with 95% confidence intervals (CI) are reported. The primary outcome was compared using the Wilcoxon

2-sample test. Statistical significance was determined if $P = < 0.05$. Data were imported into and analyzed with Microsoft Excel (version 2018.7; Addinsoft, New York, NY) and JASP (JASP Team [2019], JASP Version 0.9.2).

3 | RESULTS

3.1 | Characteristics of study subjects

During the 19-month study period 100 patients were enrolled in both the control group and study group. Baseline demographic characteristics, indications for RSI, and intubation details were similar between both groups (Table 1).

However, the oxygen delivery devices used at the commencement of preoxygenation varied between the 2 groups by around 20%, with starting device of BVM in 55% of patients in the control group and in 73% of patients in the study group (Table 1). Capnography traces were deemed to be good (rectangular) in 89% of patients, poor (non-rectangular) in 4%, and absent (flat) tracings in 1% (missing data in 6%).

3.2 | Main results

The median ETO_2 level achieved at the time of induction during RSI in the control group was 80% (interquartile range 61 to 86, overall range 73) and in the study group was 90% (interquartile range 83 to 92, overall range 41) with a median difference of 12 (95% CI: 8, 16, $P = < 0.001$)(Figure 1). The proportion of patients in whom an ETO_2 of >85% was achieved in the control group was 26% (n = 26, CI: 18% to 36%) compared to 67% in the study group (n = 67, CI: 57% to 76%) (Figure 2).

In the study group, in order to attempt to improve ETO_2 values, the oxygen delivery device was changed from NRB to BVM in 15% of patients (n = 15, flush rate = 12, non-flush rate = 3) and 11% remained with NRB in (n = 11). One patient (1%) changed from BVM to NRB and 73% remained with BVM (n = 73). Thus, the final preoxygenation device used was BVM in 87% (n = 87%). Changes in preoxygenation technique were made in 63% (n = 63) of patients. These changes were an improvement in mask seal (54%, n = 34), followed by increased duration of preoxygenation (22%, n = 14), increased oxygen flow (11%, n = 7), and increased PEEP (8%, n = 5).

In order to compare whether the preoxygenation device or the use of ETO_2 monitoring may be responsible for the improvement in preoxygenation we compared ETO_2 levels using only the BVM as the initial preoxygenation device and found the ETO_2 at induction in the control group was 80% and in the study group was 90% (Figure 3). The prevalence of hypoxemia ($SpO_2 < 90\%$) in the control group was 18% (n = 18, 95% CI: 11% to 27%) and was 8% in the study group (n = 8, 95% CI: 4% to 15%).

TABLE 1 Comparison of baseline characteristics between the control group and study group

Characteristic	Control group (n = 100)	Study group (n = 100)
Age, median (IQR), y	53 (43 to 65)	56 (40 to 69)
Male sex, no.	56	59
Indication, no.		
Pulmonary	37	30
Neurologic	25	24
Trauma	19	15
Infections (not including pulmonary)	7	9
Other	12	22
Starting preoxygenation, no.		
BVM at 15 L/min	12	33
BVM at FR	17	10
BVM PEEP at 15 L/min	13	16
BVM PEEP at FR	13	14
NRB at 15 L/min	12	6
NRB at FR	17	15
NRB NC at 15 L/min	12	5
NRB NC at FR	4	0
Intubation characteristics		
SpO_2 at commencement of preoxygenation, median, (IQR),	95 (88 to 100)	97 (87 to 100)
Preoxygenation time, median (IQR), min	12 (10 to 14)	10 (6 to 13)
Cormack/Lehane grade, median, (IQR)	1 (1 to 2)	1 (1 to 2)
Intubation attempt, % (no.)		
First	90.9 (90/99)	87.5 (84/96)
Second	9.1 (9/99)	12.5 (12/96)
Missing	1	4
Operator level of training, no.		
PGY		
1	8	7
2	27	14
≥3	65	79

BVM, bag-valve-mask; FR, flush rate; IQR, interquartile range; NC, nasal cannula; NRB, non-rebreather; PEEP, positive end-expiratory pressure; SpO_2, saturation of oxygen. PGY, Post graduate year.

4 | LIMITATIONS

This study is limited by a number of factors. This was a before/after study with a convenience sample of patients undergoing RSI in the

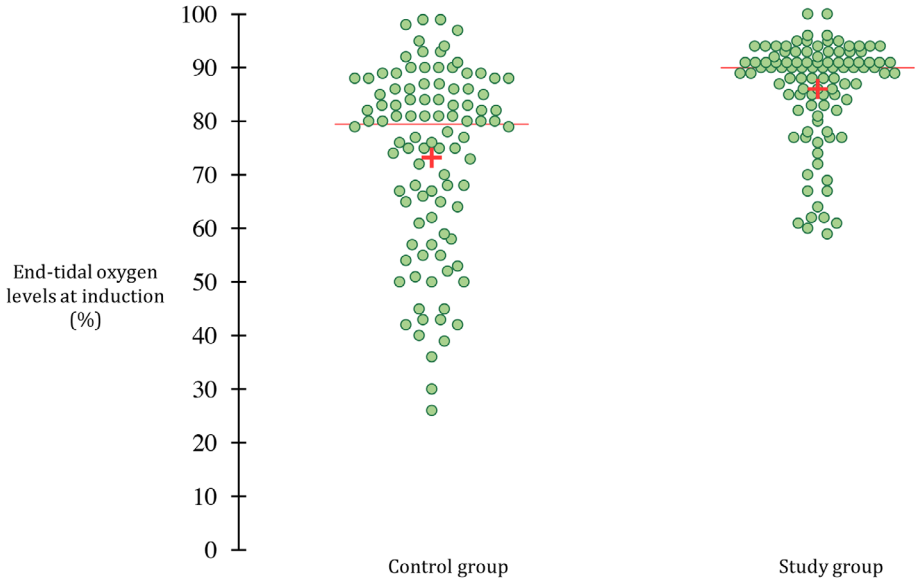


FIGURE 1 Comparison of end-tidal oxygen levels (%) at induction between the control group and study group

ED. This is one of the most stressful procedures performed in the ED, and so we gave clinicians the option to use the ETO_2 monitors when possible; however, not all patients undergoing RSI were captured during the study period and it may be argued that more critically ill patients were not captured during this study, although the reasonably large number of patients, similarity of baseline characteristics, and biological plausibility in this study may mitigate this limitation. The sampling of ETO_2 from patients using an open system with nasal cannula may also be a limitation of the study.[12] We have previously described a validation of the current gas sampling methods; however, this was on healthy volunteers and not patients.[11] Further research into the validation and accuracy of different methods of gas sampling to measure ETO_2 in patients are warranted. This is of importance when comparing open systems (using a NRB mask with nasal cannula gas sampling) to closed systems (using a BVM with an occlusive face mask seal and sidestream gas sampling). Patients with low FRC or hypoventilation may have falsely elevated ETO_2 levels that may be a limiting factor in this study, although capnography tracings were recorded to ensure adequacy of ventilation and accuracy of the data. Also, the specific relationship between the implemented changes to preoxygenation device or technique to the ETO_2 value was not recorded. Finally, this study was completed at 2 academic urban EDs where trainees performed the intubations, and therefore our results may not be generalizable to other types of practices.

5 | DISCUSSION

We have demonstrated that the introduction of ETO_2 monitoring may be associated with improvements in preoxygenation, primarily with the use of the BVM, and with a possible reduction in hypoxemic events for patients undergoing RSI in the ED. The percentage of patients achieving $ETO_2 > 85\%$ was greater when the ETO_2 monitoring was utilized, with only 26% (n = 26) reaching $ETO_2 > 85\%$ in the control group compared to 67% (n = 67%) in the study group. However, we recognize that this study does not account for the multiple confounders that relate to preoxygenation and hypoxia. Patients in both groups were similar in age, sex, indication for RSI, difficulty of intubation, and preoxygenation time, but there are many other confounders that may play a role that were not recorded in this study. These confounders include patient factors such as the airway anatomy, body habitus, hemodynamic condition, or comorbidities.[8,13,14] There are also non-patient factors such as operator experience, department pressures, RSI checklist utilization, and resource availability.[1,15]

We did observe that compared to the control group, clinicians in the study group were using BVM more frequently to commence preoxygenation (55% vs 73% respectively). An analysis of the patients using BVM as the preoxygenation device (Figure 3) reveals that the difference in ETO_2 at induction remains, indicating that the device alone is not responsible for the difference but may be related to the use of ETO_2 monitoring. It is not clear why there was an increase in use of BVM in the study group. One possibility could be that clinicians learnt by visualizing the ETO_2 result during the study that BVM produced higher ETO_2 levels and so during subsequent intubations this method of preoxygenation became the routine option.

When we analyzed the techniques utilized to improve preoxygenation, we found that the majority of clinicians (54%) used an improved mask seal to achieve higher ETO_2 levels, which can be achieved only with the BVM. Other strategies included longer preoxygenation time (22%), increased oxygen flow (11%), and the addition of PEEP (8%). Previous studies have investigated the optimal strategy for preoxygenation, but so far these have only been completed on healthy volunteers or stable patients in the OR.[16–23] Given clinicians used the BVM in nearly 90% of patients in the study group our results suggest that utilizing a BVM allows a good mask seal and real-time feedback with ETO_2 monitoring, which may therefore lead to better preoxygenation.

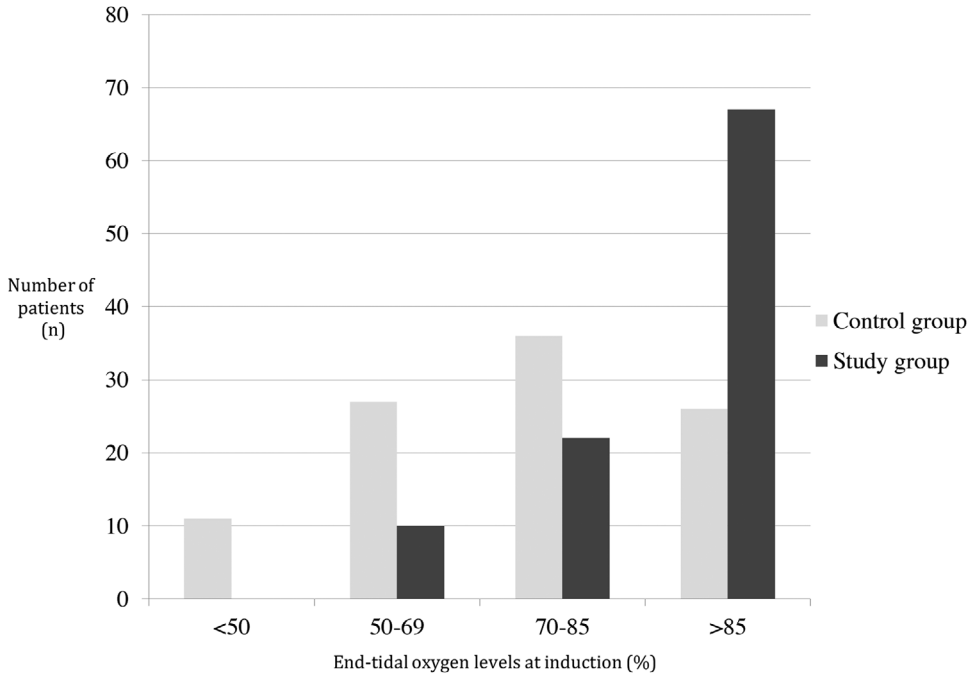
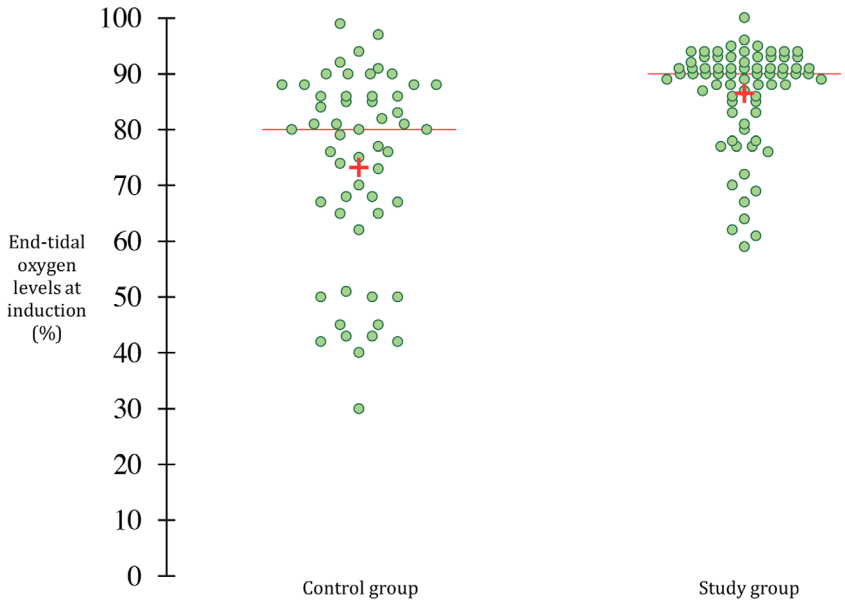


FIGURE 2 Breakdown of end-tidal oxygen levels (%) at induction between the control group and study group

FIGURE 3 Comparison of end-tidal oxygen levels (%) at induction between the control and study group using bag-valve-mask



Anesthesiologists have utilized ETO_2 monitoring for decades to optimize preoxygenation before intubation.[24] Interestingly, little evidence exists to support the use of this technology among patients undergoing RSI, and no evidence seems to exist that demonstrates clinical benefit to patients. Machlin et al studied the use of ETO_2 during preoxygenation in 200 patients undergoing elective surgery.[25] They demonstrated that using a standard time interval for preoxygenation (3 minutes) is not a reliable method to achieve optimal preoxygenation as 23% (n = 46) failed to reach the target ETO_2 level of above 90% within this time frame. The authors did not report any patient-related outcomes, for example, hypoxemia, for those who failed to be adequately preoxygenated but highlight the challenges that emergency clinicians face without the use of ETO_2 to gauge adequate preoxygenation. Despite the lack of evidence for clinical benefit to patients, ETO_2 monitoring is routinely used in the operating theatre and is recommended by current clinical practice guidelines for airway management.[10]

The aim of achieving higher ETO_2 levels is to create the largest possible reservoir of oxygen in the FRC to help maintain hemoglobin saturation during the apneic phase of RSI. RSI remains one of the most dangerous procedures performed in the ED with rates of cardiac

arrest reported to occur in 1%–2% of cases.[1,4] The reasons for this are multifactorial, but previous studies indicate that one of the major contributing factors to severe adverse events during intubation is hypoxemia.[3–5] Previous studies have demonstrated a high prevalence of oxygen desaturation during intubation in the ED. Bodily et al found that hypoxemia (SpO_2 < 90% or a further reduction in SpO_2 in patients with starting SpO_2 < 90%) occurred in 35.5% of 166 ED patients undergoing RSI.[1,2]

In our study, we found a decrease in the prevalence of hypoxemia from 18% of patients in the control group to 8% of patients in the study group by simply implementing ETO_2 monitoring. Perhaps by improving preoxygenation by utilizing ETO_2 monitoring during RSI in the ED, the frequency of hypoxemia and its associated adverse events can be reduced. Prior to any consideration for the routine use of ETO_2 in EDs a large randomized control trial (RCT) is warranted to account for the multiple confounders and answer the question of whether ETO_2 monitoring leads to an improvement in hypoxemic events during RSI in the ED. Based on data from our study to calculate the sample size for an RCT with the clinically important outcome of hypoxemia (80% power, α 0.05, 2-sided calculation) ≈350 patients in total would be required.

In summary, we have demonstrated that the use of ETO_2 monitoring in EDs is feasible and associated with potentially improved approaches to preoxygenation, specifically with the use of the BVM. A larger clinical trial is needed to further study the potential impact of ETO_2 on the preoxygenation process and the rate of hypoxemia.

CONFLICTS OF INTEREST

None of the authors declare any conflicts of interest.

AUTHOR CONTRIBUTIONS

All authors contributed to the conception and design of the study. MO, NDC, and JRW supervised the conduct of the study and data collection at their respective sites. MO, NDC, and JRW contributed to data analysis. MO drafted the manuscript and all authors had substantial contributions to produce the final manuscript. MO takes responsibility of the manuscript as a whole.

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