



Efficacy and Safety of Using High-Flow Nasal Oxygenation in Patients Undergoing Rapid Sequence Intubation

Hızlı Ardışık Entübasyon Uygulanan Hastalarda Yüksek-Akımlı Nazal Oksijenasyonun Etkinliği ve Güvenliği

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Objective: To assess the efficacy and safety of high-flow nasal oxygen (HFNO) therapy in patients undergoing rapid sequence intubation (RSI) for emergency abdominal surgery.

Methods: HFNO of 60 L.min⁻¹ at an inspiratory oxygen fraction of 1 was delivered 4 min before laryngoscopy and maintained until the patient was intubated, and correct intubation was verified by the appearance of the end-tidal CO₂ (EtCO₂) waveform. Transcutaneous oxygenation (SpO₂), heart rate and non-invasive mean arterial pressure were monitored at baseline (T0), after 4 min on HFNO (T1) and at the time of laryngoscopy (T2) and endotracheal intubation (ETI) (T3). An SpO₂ of <3% from baseline was recorded at any sampled time. The value of EtCO₂ at T3 was registered after two mechanical breaths. The apnoea time was defined as the time from the end of propofol injection to ETI. RSI was performed with propofol, fentanyl and rocuronium.

Results: Forty-five patients were enrolled. SpO₂ levels showed a statistically significant increase at T1, T2 and T3 compared with those at T0 (p<0.05); median SpO₂% (interquartile range) was 97% (range, 96%-99%) at T0, 99% (range, 99%-100%) at T1, 99% (range, 99%-100%) at T2 and 99% (range, 99%-100%) at T3. Minimal SpO₂ was 96%; no patient showed an SpO₂ of <3% from baseline; mean EtCO₂ at the time of ETI was 36±4 mmHg. Maximum apnoea time was 12 min.

Conclusion: HFNO is an effective and safe technique for pre-oxygenation in patients undergoing rapid sequence induction of general anaesthesia for emergency surgery.

Keywords: Rapid sequence intubation, pre-oxygenation, high-flow nasal oxygen therapy

Amaç: Bu çalışmanın amacı acil abdominal cerrahi için hızlı ardışık entübasyon (HAE) uygulanan hastalarda yüksek akımlı nazal oksijen (YANO) tedavisinin etkinliğini ve güvenliğini değerlendirmektir.

Yöntemler: Bir değerinde inspiratuar oksijen fraksiyonunda 60 L.min⁻¹ YANO laringoskopi öncesi 4 dakika boyunca verildi ve hasta entübe edilene kadar devam edildi. Soluk sonu CO₂ (EtCO₂) dalga biçimi görünümüyle doğru entübasyon onaylandı. Transkutanöz oksijenasyon (SpO₂), kalp atım hızı ve non-invaziv ortalama arteryel basınç başlangıçta (T0), YANO'un 4. dakikasında (T1), ve laringoskopi (T2) ve endotrakeal entübasyon (ETE) (T3) sırasında izlendi. %3'ün altındaki SpO₂ başlangıç değeri herhangi bir örnekleme zamanında kaydedildi. T3'deki EtCO₂ değeri iki mekanik solunum sonrasında kaydedildi. Propofol enjeksiyonunun sonundan ETE'ye kadar geçen süre apne süresi olarak tanımlandı. HAE propofol, fentanil ve rokuronyum ile yapıldı.

Bulgular: Çalışmaya 45 hasta dahil edildi. SpO₂ seviyelerinde T1, T2 ve T3'de T0'a göre istatistiksel olarak anlamlı bir artış gözlemlendi (p<0,05). Medyan SpO₂ yüzdesi (çeyrekler arası aralık) T0'da %97 (aralık, %96-%99), T1'de %99 (aralık, %99-%100), T2'de %99 (aralık, %99-%100) ve T3'de %99 (aralık, %99-%100) olarak bulundu. Minimal SpO₂ değeri %96 idi. Başlangıç değerinden itibaren hiçbir hastada %3'ün altında SpO₂ değeri gözlenmedi. ETE uygulanırken EtCO₂ ortalama değeri 36±4 mmHg olarak bulundu. Maksimum apne süresi 12 dakikaydı.

Sonuç: YANO, acil cerrahi için genel anestezi hızlı ardışık induksiyonu uygulanan hastalarda pre-oksijenasyon için etkili ve güvenli bir yöntemdir.

Anahtar Sözcükler: Hızlı ardışık entübasyon, pre-oksijenasyon, yüksek akımlı nazal oksijen tedavisi

Introduction

In patients undergoing elective surgery, bag/facemask ventilation is generally performed after the induction of anaesthesia for pre-oxygenation. However, when an endotracheal rapid sequence intubation (RSI) for emergency surgery is needed, options for pre- and re-oxygenation are limited because of the risk of gastric insufflation leading to increased intra-gastric pressure and raised risk of pulmonary aspiration using standard bag/facemask ventilation (1-4).

Indeed, patients undergoing RSI may benefit from pre-oxygenation to increase the oxygen reservoir in the lungs to reduce intubation-related oxyhaemoglobin desaturation (5). Thus far, optimal pre-oxygenation has usually been performed using

oxygen at an inspiratory oxygen fraction (FiO_2) of 1 using a facemask, which allows the extension of time for intubation up to 6 min (5, 6). Humidified nasal cannula high-flow oxygen therapy (HFNO) utilises an air oxygen blend heated and humidified through an active heated humidifier and delivered to the patient via a single limb heated inspiratory circuit (to avoid heat loss and condensation) using large-diameter nasal prongs (7). It allows FiO_2 delivery from 21% to 100% and generates up to 60 L.min⁻¹ flow rates (8). Theoretically, HFNO offers significant advantages over conventional oxygen in oxygenation and ventilation. Constant high-flow oxygen delivery provides steady FiO_2 and decreases oxygen dilution (9). It washes out physiologic dead spaces and generates positive end expiration pressure that augments the functional residual capacity (FRC) and improves ventilation (10, 11). Heated humidification also facilitates secretion clearance, decreases bronchospasm and maintains mucosal integrity (8). Although HFNO has been used in several clinical fields, only few studies (12-14) have used HFNO as transnasal humidified rapid-insufflation ventilatory exchange (THRIVE) at 70 L min⁻¹ to prolong the apnoea time in anaesthetised and paralysed patients. Therefore, we designed an efficacy and safety study on the use of HFNO during RSI by monitoring the oxygenation status and incidence of unwanted events.

Methods

This was a single-centre, observational, feasibility and safety study performed at the Policlinico Paolo Giaccone, University of Palermo, Italy, between September 2016 and June 2017. The ethics committee 'Comitato Etico Palermo 1' approved the study protocol. Patients aged >18 years who required RSI in general anaesthesia for urgent/emergency abdominal surgery and who were competent to give informed consent were recruited. Patients were excluded if they were aged <18 years; pregnant at any gestational time; affected by acute coronary syndrome or significant cardiovascular disease; had obstructive sleep apnoea syndrome (OSAS) with or without ventilator support with oro-tracheal or rapid-induction contraindications or unable to give informed consent. Informed consent was obtained from patients in the surgical ward or emergency department on the day of the surgery. All patients were subjected to modified RSI in which pre-oxygenation was performed with HFNO (Optiflow, Fisher & Paykel, New Zealand) for 4 min with a flow rate of 60 L.min⁻¹ at FiO_2 1, and patients were instructed to keep the mouth closed. HFNO was continued until the endotracheal tube was secured. General anaesthesia was induced with a titrated dose of propofol (2.5 mg kg⁻¹), fentanyl (3 µg kg⁻¹) and rocuronium (1.2 mg kg⁻¹). After allowing 1 min for the rocuronium to provide an effective neuromuscular block, laryngoscopy was performed. All patients continued to receive HFNO during laryngoscopy until correct intubation was verified by the end-tidal CO₂ (EtCO₂) waveform. Peripheral oxygen saturation (SpO₂), heart rate (HR) and non-invasive mean arterial pressure (nMAP) were measured at baseline (T0), af-

ter 4 min on HFNO (T1) and at the time of laryngoscopy (T2) and endotracheal intubation (ETI) (T3). SpO₂ and HR were monitored using a pulse oximeter (PM100N Nellcor™, Medtronic, USA), and EtCO₂ was detected using the Ultra-care SLP 100 Anesthesia Monitor (SPACELABS Healthcare, USA). An SpO₂ of <3% from baseline was recorded at any sampled time. EtCO₂ at T3 was registered after two mechanical breaths. The apnoea time was defined as the time from the end of induction agent injection to ETI. The primary outcome was SpO₂ and its modification at the four time points (T0–T3).

An investigator not involved in the anaesthetic management recorded the pre-oxygenation time and collected the parameters of interest. Information regarding patient characteristics and comorbidity, type of surgical intervention (grade of urgency and type of surgery), modified Mallampati score, inter-incisive distance, planned airway difficulty management and STOP-BANG (15) were recorded. The number of attempts and total duration of laryngoscopy, Cormack–Lehane laryngoscopy grade and use of any rescue manoeuvre were also recorded. The presence or absence of adverse events (severe desaturation <80%, hemodynamic instability [defined as MAP <60 mmHg with a need for vasoactive agents, cardiac arrhythmias and cardiac arrest], vomits with aspiration of gastric content and intubation failure) was reported.

Statistical analysis

Data are presented as mean ± standard deviation (SD). Non-normally distributed variables are expressed as median ± interquartile range (IQR). Data distribution was evaluated using the Kolmogorov–Smirnov test; ANOVA test was used to compare a series of repeated measurements. When the data distribution was not normal, Friedman test was used. Statistical analysis was performed using MedCalc (MedCalc Software, Ostend, Belgium). A *p* (two tails) value of <0.05 was considered significant.

Results

During the study period, 49 patients were screened, of which four were excluded because of OSAS (three patients) and a lack of informed consent (one patient). Characteristics (anthropometric data, comorbidities, type of surgery, pre-operative and intra-operative airway evaluation) of the 45 patients are shown in Table 1. SpO₂, HR and MAP at any sampled time are shown in Table 2. Apnoea times are shown in Table 3. Minimal SpO₂ was 96%; no patient showed an SpO₂ of <3% from baseline. SpO₂ levels showed a statistically significant increase at T1, T2 and T3 compared with those at T0 (*p*<0.05); median SpO₂ % (IQR) was 97% (range, 96%–99%) at T0, 99% (range, 99%–100%) at T1, 99% (range, 99%–100%) at T2 and 99% (range, 99%–100%) at T3. The mean EtCO₂ at T3 was 36.2 mmHg (SD, 4.2). Unexpected difficult intubation was observed in seven patients, but no airway rescue manoeuvres were needed in any patient. In

Table 1. Patients' characteristics and information on anaesthesia induction

	n=45
Age, years (mean, SD)	57 (18.1)
Sex, male (%)	22 (48)
BMI, kg m ⁻² (mean, SD)	26.5 (4.3)
ASA physical status (%)	
1	1 (2)
2	15 (33)
3	27 (60)
4	2 (4)
Comorbidities (%)	
Cardiovascular	24 (53)
Respiratory	15 (33)
Gastrointestinal	18 (40)
Metabolic	16 (35)
Renal	3 (6)
Type of surgery (%)	
Upper abdomen	15 (33)
Lower abdomen	30 (67)
STOP-BANG>5 (%)	1 (2)
Cormack–Lehane grade (%)	
1	11 (24)
2	27 (60)
3	7 (16)
Modified Mallampati score (%)	
1	9 (20)
2	26 (58)
3	10 (22)
Inter-incisor gap<3 cm (%)	8 (18)
Tyromental distance<6 cm (%)	5 (11)
Grade of intubator; Trainee (%)	35 (78)
Number of attempts at laryngoscopy (%)	
<2	38 (84)
>2	7 (16)
ASA: American Society of Anesthesiology; STOP-BANG: Snoring, Tired, Observed, Pressure, Body Mass Index, Age, Neck Size, Gender; BMI: body mass index; SD: standard deviation	

one patient, the maximum apnoea time was 12 min because of three intubation attempts; the haemodynamic profile was stable throughout the procedure. SpO₂ at T0–T3 was 95%, 99%, 96% and 98%, respectively. EtCO₂ at the time of intubation was 44 mmHg.

Table 2. SpO₂, HR and MAP at any sampled time

Time	SpO ₂ median (IQR)	HR (mean, SD)	MAP (mean, SD)	EtCO ₂ (mean, SD)
T0	97 (96-99)*	75 (14.3)	103 (12.4)	-
T1	99 (99-100)	77 (16.2)	97 (14.4)	-
T2	99 (99-100)	78 (16.2)	94 (16.7)	-
T3	99 (99-100)	79 (16.1)	83 (15.8)	36.4 (4.2)
*SpO ₂ levels showed statistically significant increase at T1, T2 and T3 compared with that at baseline (T0); IQR: interquartile range; SD: standard deviation; SpO ₂ : transcutaneous oxygenation; HR: heart rate; MAP: mean arterial pressure; EtCO ₂ : end-tidal carbon dioxide				

Table 3. Apnoea time during the procedure

Apnoea time (minute range)	Number of patients (%)
1–3	29 (64)
3–6	9 (20)
6–9	6 (13)
9–12	1 (2)

Discussion

This study aimed to assess the efficacy and safety of using HFNO as a pre-oxygenation method in patients undergoing RSI. The main outcome was that with the use of HFNO, the minimal SpO₂ was 96%. In addition, no patient showed an SpO₂ of <3% from baseline, while the mean EtCO₂ at the time of ETI was 36±4 mmHg.

Our results are in contrast with those of Ang et al. (16) who recently demonstrated that the Optiflow system rapidly increases EtO₂, but the variability in the extent of de-nitrogenation suggests that it is not a reliable alternative to facemask ventilation in pre-oxygenating patients. However, our results are in agreement with those of Mir et al. (12) who demonstrated that THRIVE is a practicable method for pre-oxygenating patients during RSI.

We used a continuous flow at 60 L min⁻¹ instead of 70 L min⁻¹ as performed by Mir et al. (12). It has been demonstrated that at 60 L min⁻¹, with the mouth closed, an HFNO was effective as 3 min oxygen by facemask at 10 L min⁻¹ (17). At 70 L min⁻¹, the median (IQR [range]) EtO₂ at 180 s of pre-oxygenation was 86% (84–90 [78–92]) (16). Finally, yet importantly, in our study, the oxygen flow rate was started at 60 L min⁻¹ from the beginning of pre-oxygenation. Mir et al. (12) started HFNO at 30 L min⁻¹, and the flow was increased to 70 L min⁻¹ over the course of the first minute of pre-oxygenation. A lower flow rate could also theoretically affect the carbon dioxide washout (18). Nevertheless, our EtCO₂ values were not higher than their PaCO₂ values obtained after intubation.

Interestingly, one patient had an apnoea time of 720 s. Patel et al. (13) have shown that in patients with known or anticipated difficult airways, oxygenation using the THRIVE technique is associated with prolonged apnoea time before arterial oxygen desaturation. The median (IQR [range]) apnoea time was 14 min (9-19 [5-65]). No patient experienced arterial desaturation of <90%. As explained by Mir et al. (12), this fact may be related to both effective supply of oxygen and other mechanisms, such as apnoeic ventilation (19-21). In addition, during pre-oxygenation with HFNO, end expiratory lung volume and FRC increased and dead space decreased (18, 22-25).

It can be argued that EtCO₂ values do not reflect actual alveolar carbon dioxide values (12). However, only 33% of patients were affected by chronic respiratory diseases (26). In addition, although pH was not measured, EtCO₂ values in the present study were far from those causing severe respiratory acidosis as was shown using THRIVE in patients under apnoeic oxygenation for laryngeal surgery (27).

We found a stable haemodynamic profile in our patients during RSI. It can be speculated that HFNO maintaining suitable arterial blood gases led to good haemodynamic stability.

The present study has several limitations: (1) We did not measure EtO₂. The efficacy of pre-oxygenation is dependent on the inspired O₂ concentration, duration of pre-oxygenation, alveolar ventilation and FRC and EtO₂ (16, 17). It has been argued that pre-oxygenation can be claimed to be effective only if fractional EtO₂ of >90% is achieved. However, measuring EtO₂ may have methodological issues (12, 16, 17, 28), and the concept of pre-oxygenation is not related only to a fractional ETO₂ of >90%. Measurements of pre-oxygenation have focused on EtO₂ of >90% because this is the most readily measurable, whereas a more accurate measure of the efficacy of pre-oxygenation is the arterial oxygen partial pressure. Although transcutaneous oxygen (PtO₂) was monitored in our study (14), SpO₂ assessment has been found to be at least more favourable than PtO₂ as a non-invasive method to analyse blood oxygenation (14). Additionally, we can say that SpO₂ is more important than PaO₂ regarding the effect on oxygen delivery to tissues (14). Mir et al. (12) did not report any systematic SpO₂ value during the procedure. We speculate that SpO₂ assessment shows benefits compared with the analysis of multiple arterial sampling (14), which would not be realistic in the context of RSI. (2) The study was not randomised as opposed to facemask oxygenation performed by Mir et al. (12). In fact, our results do not indicate the superiority or inferiority of HFNO over conventional modes of pre-oxygenation. Although we acknowledge this fact, our ethical committee, at the time when the study was designed, did not approve a randomised controlled trial unless an anticipated efficacy and safety study was conducted.

Conclusion

High-flow oxygen therapy seems to be safe and effective for pre-oxygenation and for maintaining oxygenation in patients receiving RSI for urgent/emergency abdominal surgery. Future randomised trials are needed to assess the range of apnoea time in different patient populations (12).

Ethics Committee Approval: Ethics committee approval was received for this study from the Ethics Committee of the University of Palermo.

Informed Consent: Written informed consent was obtained from patients who participated in this study.

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References

1. Weingart SD. Preoxygenation, reoxygenation, and delayed sequence intubation in the emergency department. *J Emerg Med* 2011; 40: 661-7. [\[CrossRef\]](#)
2. Russotto V, Cortegiani A, Raineri SM, Gregoretti C, Giarratano A. Respiratory support techniques to avoid desaturation in critically ill patients requiring endotracheal intubation: A systematic review and meta-analysis. *J Crit Care* 2017; 41: 98-106. [\[CrossRef\]](#)

3. Frerk C, Mitchell VS, McNarry AF, Mendonca C, Bhagrat R, Patel A, et al. Difficult Airway Society 2015 guidelines for management of unanticipated difficult intubation in adults. *Br J Anaesth* 2015; 115: 827-48. [\[CrossRef\]](#)
4. Gregoret C, Pisani L, Cortegiani A, Ranieri VM. Noninvasive ventilation in critically ill patients. *Critical Care Clinics* 2015; 31: 435-57. [\[CrossRef\]](#)
5. Nimmagadda U, Salem MR, Crystal GJ. Preoxygenation: Physiologic Basis, Benefits, and Potential Risks. *Anesth Analg* 2017; 124: 507-17. [\[CrossRef\]](#)
6. Wong DT, Yee AJ, Leong SM, Chung F. The effectiveness of apneic oxygenation during tracheal intubation in various clinical settings: a narrative review. *Can J Anaesth* 2017; 64: 416-27. [\[CrossRef\]](#)
7. Spoletini G, Alotaibi M, Blasi F, Hill NS. Heated Humidified High-Flow Nasal Oxygen in Adults: Mechanisms of Action and Clinical Implications. *Chest* 2015; 148: 253-61. [\[CrossRef\]](#)
8. Nishimura M. High-Flow Nasal Cannula Oxygen Therapy in Adults: Physiological Benefits, Indication, Clinical Benefits, and Adverse Effects. *Respiratory Care* 2016; 61: 529-41. [\[CrossRef\]](#)
9. Ritchie JE, Williams AB, Gerard C, Hockey H. Evaluation of a humidified nasal high-flow oxygen system, using oxygraphy, capnography and measurement of upper airway pressures. *Anaesth Intensive Care* 2011; 39: 1103-10.
10. Parke R, McGuinness S, Eccleston M. Nasal high-flow therapy delivers low level positive airway pressure. *Br J Anaesth* 2009; 103: 886-90. [\[CrossRef\]](#)
11. Moller W, Celik G, Feng S, Bartenstein P, Meyer G, Oliver E, et al. Nasal high flow clears anatomical dead space in upper airway models. *J Appl Physiol (1985)* 2015; 118: 1525-32. [\[CrossRef\]](#)
12. Mir F, Patel A, Iqbal R, Cecconi M, Nouraei SAR. A randomised controlled trial comparing transnasal humidified rapid insufflation ventilatory exchange (THRIVE) pre-oxygenation with facemask pre-oxygenation in patients undergoing rapid sequence induction of anaesthesia. *Anaesthesia* 2017; 72: 439-43. [\[CrossRef\]](#)
13. Patel A, Nouraei SAR. Transnasal Humidified Rapid-Insufflation Ventilatory Exchange (THRIVE): a physiological method of increasing apnoea time in patients with difficult airways. *Anaesthesia* 2015; 70: 323-9. [\[CrossRef\]](#)
14. Ekkernkamp E, Welte L, Schmoor C, Huttmann SE, Dreher M, Windisch W, et al. Spot check analysis of gas exchange: invasive versus noninvasive methods. *Respiration* 2015; 89: 294-303. [\[CrossRef\]](#)
15. Chung F, Abdullah HR, Liao P. STOP-Bang Questionnaire: A Practical Approach to Screen for Obstructive Sleep Apnea. *Chest* 2016; 149: 631-8. [\[CrossRef\]](#)
16. Ang KS, Green A, Ramaswamy KK, Frerk C. Preoxygenation using the Optiflow system. *Br J Anaesth* 2017; 118: 463-4. [\[CrossRef\]](#)
17. Pillai A, Daga V, Lewis J, Mahmoud M, Mushambi M, Bogod D. High-flow humidified nasal oxygenation vs. standard face mask oxygenation. *Anaesthesia* 2016; 71: 1280-3. [\[CrossRef\]](#)
18. Moller W, Celik G, Feng S, Bartenstein P, Meyer G, Oliver E, et al. Nasal high flow clears anatomical dead space in upper airway models. *J Appl Physiol (1985)* 2015; 118: 1525-32. [\[CrossRef\]](#)
19. Weingart SD, Levitan RM. Preoxygenation and prevention of desaturation during emergency airway management. *Ann Emerg Med* 2012; 59: 165-75.e1.
20. Ramachandran SK, Cosnowski A, Shanks A, Turner CR. Apneic oxygenation during prolonged laryngoscopy in obese patients: a randomized, controlled trial of nasal oxygen administration. *J Clin Anesth* 2010; 22: 164-8. [\[CrossRef\]](#)
21. Pillai A, Chikhani M, Hardman JG. Apnoeic oxygenation in pregnancy: a modelling investigation. *Anaesthesia* 2016; 71: 1077-80. [\[CrossRef\]](#)
22. Parke R, McGuinness S, Eccleston M. Nasal high-flow therapy delivers low level positive airway pressure. *Br J Anaesth* 2009; 103: 886-90. [\[CrossRef\]](#)
23. Parke RL, Bloch A, McGuinness SP. Effect of very-high-flow nasal therapy on airway pressure and end-expiratory lung impedance in healthy volunteers. *Respiratory Care* 2015; 60: 1397-403. [\[CrossRef\]](#)
24. Corley A, Caruana LR, Barnett AG, Tronstad O, Fraser JF. Oxygen delivery through high-flow nasal cannulae increase end-expiratory lung volume and reduce respiratory rate in post-cardiac surgical patients. *Br J Anaesth* 2011; 107: 998-1004. [\[CrossRef\]](#)
25. Mundel T, Feng S, Tatkov S, Schneider H. Mechanisms of nasal high flow on ventilation during wakefulness and sleep. *J Appl Physiol (1985)* 2013; 114: 1058-65. [\[CrossRef\]](#)
26. Dogan NO, Sener A, Gunaydin GP, Icme F, Celik GK, Kavakli HS, et al. The accuracy of mainstream end-tidal carbon dioxide levels to predict the severity of chronic obstructive pulmonary disease exacerbations presented to the ED. *Am J Emerg Med* 2014; 32: 408-11. [\[CrossRef\]](#)
27. Gustafsson I-M, Lodenius A, Tunelli J, Ullman J, Jonsson Fagerlund M. Apnoeic oxygenation in adults under general anaesthesia using Transnasal Humidified Rapid-Insufflation Ventilatory Exchange (THRIVE) - a physiological study. *Br J Anaesth* 2017; 118: 610-7. [\[CrossRef\]](#)
28. Mir F, Patel A, Iqbal R, Cecconi M, Nouraei S. THRIVE, rapid sequence induction and oxygenation. A reply. *Anaesthesia* 2017; 72: 1033-5. [\[CrossRef\]](#)