

Apnoeic oxygenation with high-flow oxygen for tracheal resection and reconstruction

Nguyen Minh Ly, Tong Xuan Hung, Ngo Vi Hai,
Dang Trung Dung, Dinh Thi Thu Trang,
Nguyen Truong Tho, Nguyen Quang Truong,
Dam Van Khai, Nguyen Quoc Khanh, Ngo Van Dinh

108 Military Central Hospital

Summary

Objective: This study aimed to evaluate the effectiveness of high-flow oxygen as the sole method of gas exchange in apnoeic conditions during anastomosis construction. **Subject and method:** Between April 2019 and August 2020, 16 patients with tracheal stenosis, ages ranging from 19 to 70, underwent tracheal resection and reconstruction. Patients received total anesthesia and neuromuscular blocking agents for the duration of their surgery. During the anastomosis phase using high flow oxygen of 35 - 40 l.min⁻¹ delivered across an open tracheal with an endotracheal tube (ETT) at the glottis in apnoeic conditions. **Result:** The mean (SD) apnoea time was 20.91 ± 2.53 mins. Mean (SD) time anastomosis was 22.9 ± 2.41 mins. The saturation of oxygen was stable during all procedures at 98-100%. One patient experienced an oxygen desaturation episode to a value between 88% and 90% lasting less than 2 mins. Arterial blood gas analysis showed that there was hypercapnia and acidosis acute respiratory with pH 7.25 ± 0.04; PaCO₂ 67.57 ± 14.71mmHg, and PaO₂ 167.12 ± 76.23mmHg after 10 mins of apnoea and pH was 7.17 ± 0.05; PaCO₂ 79.63 ± 13.39mmHg and PaO₂ 186.19 ± 60.14mmHg after 20 mins apnoea, respectively. However, after 15 mins of ventilation, the parameters are ultimately returned to normal. The blood pressure and heart rate are stable at times. All 16 patients were extubated early and safely at the end of the operation. There were no complications, such as bleeding, hemothorax, pneumothorax, or barotrauma. **Conclusion:** High-flow oxygen across an open tracheal under apnoeic conditions can provide a satisfactory gas exchange to allow tubeless anesthesia for tracheal resection and reconstruction. The surgical field is ultimately in spacious, optimal conditions for anastomosis.

Keywords: Tracheal resection, high-flow oxygen, apnoeic oxygenation.

1. Background

Tracheal stenosis is a rare disease often caused by prolonged intubation, primary or secondary tumors, and invasive thyroid cancer. They are life-threatening if not adequately treated [1]. Tracheal resection and reconstruction are the most effective treatment, but the difficulties are

surgery and maintaining ventilation performed on the patient's same airway.

Based on the severity and location of the stenosis and the type of surgical procedure, there may be a variety of choices for perioperative airway management such as a facemask, laryngeal mask airway, tracheal intubation tube, jet ventilation with the small catheter, cardiopulmonary bypass, and extracorporeal membrane oxygenation [9].

Correspondence to: Nguyen Minh Ly - Department of Anesthesia, 108 Military Central Hospital

Email: nguyennyminhly@yahoo.com

The methods like intubation or using small-sized high-frequency catheters often cause a narrow surgical field and limited vision.

Recently, high-flow nasal and high-flow oxygen delivery device attached directly to a laryngeal mask or tracheal tube has begun to be applied to provide oxygen for some laryngeal surgery without intubation as well as prolonging the apnea time in the difficult intubation [2], [4], [7], [8], [10].

We also applied this method during the tracheal anastomosis period for tracheal resection and reconstruction, aiming to create an optimal surgical field without endotracheal intubation and ventilation.

This study aimed to evaluate the gas exchange efficiency and safety of apnoeic oxygenation of high-flow oxygen method, using for airway management at 16 patients tracheal resection and reconstruction.

2. Subject and method

From April 2019 to August 2020, 16 patients were diagnosed with tracheal stenosis caused by cancer invasive thyroid cancer, tracheal stenosis after intubation, and upper tracheal tumor. They were scheduled for tracheal resection and reconstruction surgery using high-flow oxygen combined for airway management at the Department of Anesthesia of 108 Military Central Hospital.

2.1. Preoperative preparation and materials

The equipment and anesthesia agents:

Anesthesia machine, multi-parameter monitor, TCI (target-controlled infusion) system.

High-flow oxygen system

Flexible endotracheal tubes (ETT), ID sizes from 4.0 to 7.5. The Proseal laryngeal mask size 3 - 5. Catheters with diameters of 3.3 - 4.7mm (Cook Airway Exchange Catheter) can pass

through narrow positions for high-frequency jet ventilation.

Anesthesia agents: Propofol, rocuronium, fentanyl, morphine.

Emergency instruments.

Evaluation of patients:

Evaluation of patients includes general history and physical examination, with particular attention to the airway and pulmonary systems, and analyzing arterial blood gases.

To prepare for any possible airway emergency during the induction and maintenance of anesthesia, it is essential to carefully evaluate the stenosis or tumor's exact location and the obstruction degree preoperatively.

Magnetic resonance imaging (MRI) scans provide greatest diameter of the tracheal stenosis or tumor, minimum tracheal diameter, the length of the lesion, the distal from the vocal cord to the tracheal stenosis, from stenosis to the carina...

Bronchoscopy defines the character of the tracheal stenosis or tumor surrounding tracheal by a direct vision that can be predicted capacity intubated and operated.

2.2. Method

Before the induction, it must be considered that spontaneous breathing or mechanical ventilation is likely to be possible through the stenosis with general anesthesia. Nevertheless, severe airway obstruction may occur during the induction of general anesthesia, and thus the appropriate backup method will be required to prevent disaster.

If possible, mask ventilation under general anesthesia, preoxygenation with 6 l.min⁻¹ 100% for 5 mins, slow and gentle induction of anesthesia following by IV: Fentanyl 2µg/kg, propofol TCI Cp 3.5 - 4µg/ml, rocuronium 0.6mg/kg.

The positive pressure ventilation was secured via facemask, inserting the endotracheal tube into the tracheal so that the tip of the endotracheal tube

is close to the stenosis if the distance from the vocal cord to the lesion > 2cm. If mild tracheal stenosis, we use tube 5.0 - 6.0Fr passed through the narrow position.

If the distance from the vocal cord to the lesion very short < 2cm, the Proseal laryngeal mask (LMAP) is placed, inserted sonde gastric through the second tube of LMAP, continuous ventilation via LMAP.

If the patient has severe stenosis and airway obstruction, we use catheters with diameters of 3.3 - 4.7mm. (Cook Airway Exchange Catheter) put through narrow positions for high-frequency jet ventilation with 100% oxygen.

In case the patient has a tracheostomy, ventilating through the tube of tracheostomy.

Anesthesia was maintained intravenously by the combination of propofol using Target Controlled Infusion (TCI) method 3.5 - 4µg/ml, fentanyl 2 - 3µg/kg/h, rocuronium 0.2mg/kg/h, solumedron 2mg/kg.

Once the airway is opened, the surgeon inserts a flexible endotracheal tube 6.5 - 7.5Fr into the distal airway and ventilates. They were completely removing the laryngeal mask, endotracheal tube, catheter Cook. Setting a waiting endotracheal tube at glottis and connecting to the high-flow oxygen system.

Once the tracheal lesion is removed, and the surgeon starts anastomosis, open the oxygen flow 35 - 40 l.min⁻¹ so that the oxygen is provided across the open trachea. Adjust for the direction of oxygen flow straight to the distant trachea. During this period, the patient is still under general anesthesia, neuromuscular blocking agents, and completely stopped breathing completely. Monitor SpO₂ and arterial blood gases. If SpO₂ drops < 90%, ventilation

supports 100% oxygen with an endotracheal tube at the tracheal distance. When the trachea is nearly closed, push the endotracheal tube so that the cuff passes over the anastomosis and normalizes the ventilation.

End of surgery: Extubation is the primary goal because postoperative mechanical ventilation is associated with anastomotic failure; the reconstructed airway may be tenuous. When the patients awake and cooperative, all vital parameters were normal limits; patients should be extubated on the table as soon as possible.

2.3. Monitoring and evaluation criteria

Characteristics of the patients: Age, height, body weight, classification of dyspnea according to MMRC (Modified Medical Research Council), degree of the physical state of the patients ASA (American Society of Anesthesiologists). Degree of tracheal stenosis according to Cotton- Mayer

Surgical characteristics: Anesthesia time, surgery time.

The method of maintaining ventilation.

The anastomosis time: From the open trachea to the end closed airway.

Apnoeic time using high flow.

The vital parameters were monitored continuously: Heart rate, SpO₂, EtCO₂, blood pressure. All results are expressed as mean ± SD, blood gases analysis (ABG) at 5 periods: T₀: Before the anesthesia; T₁: Before using high flow. T₂: After using high-flow 10 mins; T₃: After 20 mins of high-flow and T₄: Finish the high-flow 15 mins.

The complications during surgery include airway obstruction, tumor peeling, gas overflow, pneumothorax.

3. Result

Table 1. Characteristics of the patients

Age (years)	Height (cm)	Weight (kg)	Gender	ASA
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X ± SD Min-Max	X ± SD Min-Max	X ± SD Min-Max	Male n (%)	Female n (%)	II n (%)	III n (%)	IV n (%)
46.50 ± 16.42 (19 - 70)	160.06 ± 5.16 (152 - 168)	50.50 ± 3.39 (43 - 55)	09 (56.25)	07 (43.75)	06 (37.5)	08 (50)	02 (12.5)

Comments: The mean age of the group was 46.50 ± 16.42 years. The proportion of males in the group (56.25%) was higher than females (43.75%). Most patients were ASA III, 02 patients were ASA IV, who have life-threatening dyspnea requiring emergency surgery.

Table 2. Cause of tracheal stenosis

Causes	Number of patients (n)	Percentage %
After prolong intubaion	09	56.25
After tracheotomy	02	12.5
Tracheal tumour	01	6.25
Thyroid cancer invasion	04	25
Total	16	100

Table 3. Classification of dyspnea (modified Medical Research Council)

Dyspnea scale	Grade 1	Grade 2	Grade 3	Grade 4	Total
n	3	6	5	2	16
%	18.75	37.5	31.25	12.5	100

Table 4. Degree of tracheal stenosis according to Cotton-Mayer

Degree of tracheal stenosis (%)	Number of patients	Percentage %
Grade1: Luminal narrowing < 50%	03	18.75
Grade 2: Luminal narrowing 51.... < 71%	06	37.5
Grade 3: Luminal narrowing 71.... < 99%	05	31.25
Grade 4: Luminal narrowing > 99%	02	12.5
Total	16	100

Table 5. Surgical characteristics

Time (mins)	Min- Max	Value X ± SD
Duration of anesthesia	115- 220	170.69 ± 31.89
Duration of surgery	95 -185	134.56 ± 21.18
Duration of anastomosis	17 - 28	22.9 ± 2.41
Oxygen high-flow (apnea time)	16- 28	20.91 ± 2.53

Comments: The average of apnea time was 20.91 ± 2.53 mins that's mean the time enough for anastomosis.

Table 6. Airway management

Period	Methods	Number of patients	Percentage %	Total
Induction (before dissection)	Intubation above the lesion	04	25	100%
	Intubation through the lesion	06	37.5	
	Laryngeal mask	03	18.75	
	At tracheostomy	02	12.5	
	The Small catheter for jet entilation	01	6.25	
Open airway (Anastomosis)	High-flow oxygen single	15	93.75	100%
	High-flow oxygen combined ventilation intermittent	01	6.25	

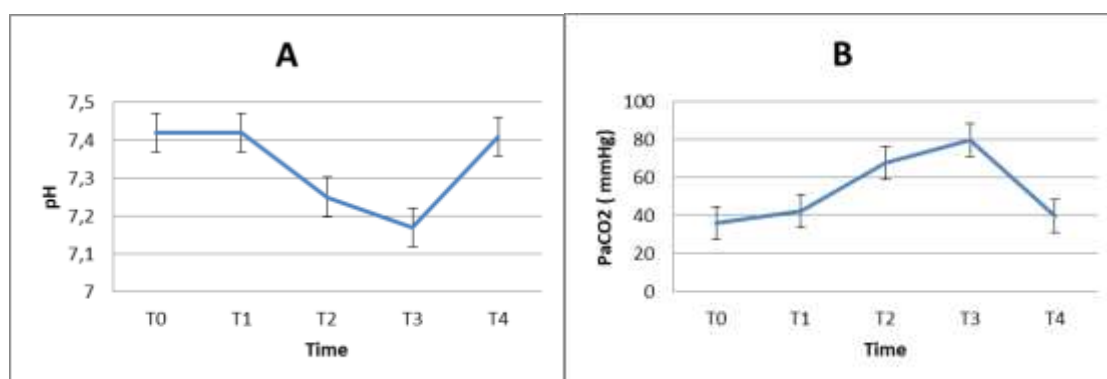
Comments: There may be a variety of choices for perioperative airway management. In the research, there was one patient with hypoxia who must use high-flow oxygen combined ventilation intermittent through endotracheal tubes at the distant tracheal.

Table 7. Arterial blood gas exchange data

Time Data	T ₀ $\bar{X} \pm SD$	T ₁ $\bar{X} \pm SD$	T ₂ $\bar{X} \pm SD$	T ₃ $\bar{X} \pm SD$	T ₄ $\bar{X} \pm SD$
pH	7.42 \pm 0.02	7.42 \pm 0.06	7.25 \pm 0.04*	7.17 \pm 0.05*	7.41 \pm 0.06
PaCO ₂ (mmHg)	35.95 \pm 3.32	42.17 \pm 9.63	67.57 \pm 14.71*	79.63 \pm 13.39*	39.48 \pm 5.17
PaO ₂ (mmHg)	101.1 \pm 3.54	220.38 \pm 62.08*	167.12 \pm 76.23*	186.19 \pm 60.14*	217.63 \pm 74.63*
Lactate	1.0 \pm 0.42	1.16 \pm 0.51	1.06 \pm 0.6	1.06 \pm 0.58	1.26 \pm 0.87
HCO ₃ ⁻ (mEq/L)	23.35 \pm 3.75	27.34 \pm 5.45	29.79 \pm 6.73*	30.03 \pm 5.5*	25.98 \pm 4.78
BE (mEq/L)	2.4 \pm 0.99	4.57 \pm 6.32	3.23 \pm 6.08	2.91 \pm 5.31	2.22 \pm 4.99

*: p<0.05 compared with T₀

Comments: During the apneic period with high-flow (T₂, T₃), PaO₂ increased significantly compared to the time of T₀; acute respiratory acidosis clearly showed pH decreased, PaCO₂ and HCO₃⁻ increased. However, these data return to normal at the time of T₄.



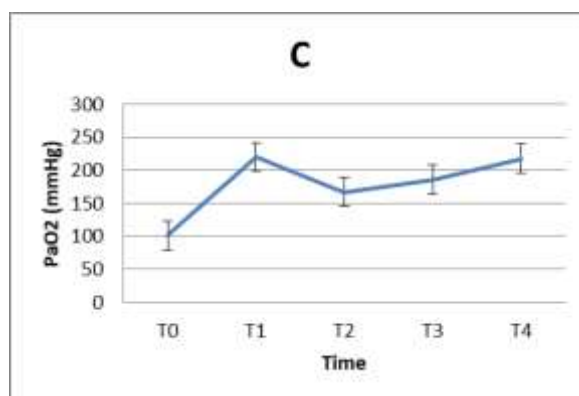


Figure 1. (A) pH, (B) partial pressure of arterial carbon dioxide (PaCO₂) and (C) partial pressure of arterial oxygen (PaO₂) at T₀: Before anesthesia; T₁: Before using high flow. T₂: After using high flow 10 mins; T₃: After 20 mins of high flow and T₄: Finish the high-flow 15 mins.

Table 8. Change of respiratory and hemodynamic

Time Data	T ₀ $\bar{x} \pm SD$	T ₁ $\bar{x} \pm SD$	T ₂ $\bar{x} \pm SD$	T ₃ $\bar{x} \pm SD$	T ₄ $\bar{x} \pm SD$
Heart rate (beat/min)	87.3 ± 7.5	76.58 ± 3.42	78.5 ± 4.89	79.17 ± 6.19	77.17 ± 5.62
MAP (mmHg)	85 ± 12	74.5 ± 3.78	74.33 ± 5.14	75.42 ± 6.43	77.16 ± 3.76
SpO ₂ (%)	94 ± 3.7	99.83 ± 0.58*	99.17 ± 1.11*	99.67 ± 0.49*	99.66 ± 0.65*
EtCO ₂ (mmHg)		35.67 ± 3.39		55.4 ± 7.16 †	33.58 ± 2.78

*: p<0.05 compared with T₀; † p<0.05 compared with T₁.

Comments: Heart rate and MAP after high-flow oxygen was decreased significantly compared with T₀ (before induction), SpO₂ at T₀ was significantly lower than T₁, T₂, T₃. After 20 mins of high flow (T₃), etCO₂ was significantly higher than before and after using high-flow oxygen.

Table 9. Side effects

Complications	Number of patients (n)	Percentage %
Acute respiratory distress (PaO ₂ < 60, SpO ₂ < 90)	1	6.25
Acute respiratory acidosis (PaCO ₂ > 50mmHg)	16	100
Respiratory obstruction	0	0
Arrhythmia	0	0
Pneumothorax, hemothorax	0	0

Comments: Side effects during surgery were acute respiratory acidosis in all 16 patients, 01 patients with hypoxia. There were no complications of arrhythmia, pneumothorax, hemothorax.

4. Discussion

The course of anesthesia was divided into five phases. First: induction and intubation, a critical period. Second: Dissection, a period of relative calm during which lesion is defined.

Third: open airway, a crucial period in which anastomosis is being constructed. Fourth: Closure and emergence and fifth: extubation.

Most of the patients with narrow airways admission to hospital due to shortness of breath, there are 03 cases of patients who can not lie, 02 cases of life-threatening who have to do the emergency surgery.

Induction is a critical period that needs to combine many flexible methods to control ventilation. The results in table 5 show that depending on the severity and location of the stenosis, there may be various choices for airway management in the period of induction. The endotracheal tube may be placed above (25%) or through the lesion (37.5%), there are 3 patients (18.75%) showing the distance from the vocal cord to the lesion very short (< 2cm). We had to use a laryngeal mask (LMAP). It is an effective solution in the first phase.

Patients with severe tracheal stenosis > 90% with a high risk of airway obstruction ensure safety (the Bricker DL [3]); Chiu CL [5] applied the method of cardiopulmonary bypass. Although it is an easy way to ensure gas exchange, systemic anticoagulation theoretically increases bleeding risk, especially if the dissection is extensive, and lung manipulation is unavoidable.

Before the induction, we prepared all emergency equipments to prevent tracheal obstruction. Small-sized catheters to pass through the narrow for jet ventilation, surgeons, as well as surgical facilities, are prepared for tracheotomy. In 2 of our patients with tracheal stenosis > 90%, 01 patients can be intubated and ventilated above the narrow space. For the other, we had to use a small jet catheter pushed through the stenosis for jet ventilation with oxygen pure 100% before the open airway phase.

The open airway phase is a critical period in which anastomosis is being constructed. Once the airway is opened, a flexible endotracheal tube 6.5 -7.5Fr was inserted to the distal airway

and ventilated, waiting for ET through the glottis and connected to the high-flow oxygen system. When the surgeon started anastomosis, open the oxygen flow 35 - 40 l.min⁻¹ so that the oxygen is provided across the surgical field to the distant trachea. The time for apnoeic oxygenation or the time of anastomosis was 16-28 mins, but this time depends on the surgeon's experience. If the apnea time is too long, which can cause unsafety like hypercapnia or hypoxia ($SpO_2 < 90\%$, blood $pH < 7.1$).

The results of Table 7 show that before intubation, arterial blood gas had mild respiratory acidosis, oxygen pressure decreased significantly compared to the time of T_0 , acute respiratory acidosis clearly showed pH decreased, $PaCO_2$ and HCO_3^- increased. However, these data return to normal at the time of T_4 .

In the period of anastomosis being constructed 10 and 20 mins (T_2 , T_3), with high flow oxygen 35 - 40 l.min⁻¹, the blood oxygen pressure improved significantly compared to the time of T_0 with $PaO_2 > 170$ mmHg. The acute respiratory acidosis present, the lowest at T_3 with pH was 7.17 ± 0.05 , and $PaCO_2$ was 79.63 ± 13.39 HCO_3^- increased significantly but returned to normal immediately after 15 mins mechanical ventilation at T_4 .

Tracheal resection and reconstruction require the anesthesiologist and the surgeon to share the airway. The greatest benefit of high flow is creating a free surgical field, optimal conditions for anastomosis, and no interruption of surgery without endotracheal intubation and ventilation.

Apnoeic oxygenation is the ability to oxygenate a patient in the absence of lung movement. At the onset of apnoea, there is a continued transfer of oxygen from the alveolus to the blood in order to fulfill the metabolic demands of the body. This oxygen transfer leads to emptying of alveoli and a fall in alveolar pressure, which is initially compensated for by reducing

alveolar volume from elastic recoil and by carbon dioxide movement from blood to the alveolus. These compensatory mechanisms are rapidly exhausted, and a pressure gradient develops for oxygenation between the upper airway and the alveolus [4].

Egan M et al also applied oxygen 100% at a flow-rate of 40 l.min⁻¹ delivered across an open trachea in an apnoeic female patient with subglottic tracheal stenosis. This permitted 42 mins of uninterrupted surgery; oxygen saturations remained above 96% during the apnoeic period and arterial blood gas parameters within acceptable limits. No urgent interruption of surgery or rescue mechanical ventilation was required [7].

Lyons C et al applied the study between November 2016 and May 2017. 28 patients underwent tubeless laryngeal or tracheal surgery under apnoeic conditions with high-flow nasal oxygen. The median apnoea time was 19 (15 - 24) mins. Four patients experienced a transient episode of oxygen desaturation to a value between 85% and 90%. The partial pressure of carbon dioxide (PaCO₂) of 6.29 (0.71) kPa at baseline and 9.44 (1.12) kPa after 15 min of apnoea. The authors concluded that high-flow nasal oxygen under apnoeic conditions could provide a satisfactory gas exchange to allow tubeless anesthesia for laryngeal surgery [4].

The safe breathing time was calculated from the time when the patient stopped breathing until SaO₂ decreased < 90%. Alveoli will continue to take up oxygen even without diaphragmatic movements or lung expansion. In a healthy apnoeic patient, ~200-250ml/min oxygen will move from the alveoli into the bloodstream, only 8 - 20ml/min of carbon dioxide moves into the alveoli during apnea, with the remainder being buffered in the bloodstream given the high water solubility of CO₂. In healthy people under ideal circumstances, PaO₂ can be maintained at > 100mmHg for up to 100 mins without a single breath. However, the lack of ventilation will

eventually cause marked hypercapnia and significant acidosis, many authors have demonstrated that acute respiratory acidosis within pH > 7.15 is the safety limits are acceptable in the absence of contraindications [6], [7].

The results of tables 8 and 9 showed that during procedure hemodynamics, oxygen pressure, oxygen saturation (SpO₂) were within normal limits. Only 1 patient with hypoxia during surgery is the case of patients with pneumonia in the right lower lobe should support oxygen through the distant airway.

High-flow oxygen under apnoeic conditions can provide a satisfactory gas exchange with gas exchange data improved than before surgery. The surgical field is especially completely spacious, optimal conditions for anastomosis, and no interruption of operation without endotracheal intubation. There were no complications of arrhythmia, pneumothorax, hemothorax.

5. Conclusion

High-flow oxygen across an open trachea in apnoeic conditions can provide a satisfactory gas exchange to allow tubeless anesthesia for tracheal resection and reconstruction. The surgical field is ultimately in spacious, optimal conditions for anastomosis.

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