Application of high-flow nasal cannula oxygenation in the induction of general anesthesia by direct providers: A case series

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Research Article

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Application of high-flow nasal cannula oxygenation in the induction of general anesthesia by direct providers: A case series

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Abstract

Background: Pressurized mask-assisted ventilation is commonly used during general anesthesia, which often requires the cooperation of two anesthesiologists and creates a severe shortage of anesthesiologists. High-flow nasal cannula oxygenation (HFNCO) is reportedly effective in perioperative airway management, but its safety and efficacy in the induction of general anesthesia by direct providers have not been confirmed.

Methods: Twelve patients were enrolled in our study. Their vital signs were recorded before surgery (T_0), and HFNCO was continuously applied after admission. Blood gas analysis results were recorded before pre-oxygenation (T_1), during anesthetic induction (T_2), and before mechanical ventilation (T_3).

Results: The mean arterial partial pressure of oxygen (PaO_2) was 86.6±26.0, 245.3±90.6, and 170.0±99.4 mmHg at T_1, T_2, and T_3, respectively, and the lowest pulse oxygen saturation (SpO_2) was 92% at T_3. The mean arterial partial pressure of carbon dioxide ($PaCO_2$) was 39.0±6.2, 40.0±5.7, and 50.2±8.7 mmHg, respectively; the highest was 71.1 mmHg. The mean pH was 7.40±0.02, 7.39±0.05, and 7.35±0.06, respectively. One patient switched to pressurized mask-assisted ventilation because of severe hypoxemia (lowest SpO_2, 82%) during apnea oxygenation.

Conclusions: HFNCO significantly improves oxygenation levels without severe hypercapnia and can be safely applied to general anesthesia induction by direct providers.

Keywords: high-flow nasal cannula oxygenation; general anesthesia; apnea oxygenation; hypoxemia; hypercapnia

Background

Induction of general anesthesia is often necessary to apply apnea oxygenation technology and ensure oxygenation. In the usual method, the patient inhales pure oxygen at 4 to 5 L/min and is instructed to take three to five deep breaths or calmly breathe for 2 minutes before induction to replace the nitrogen in the lungs with pure oxygen, improve the oxygen reserve, and prolong the asphyxia[1, 2]. The patient does not develop severe hypoxemia from the onset of the muscle relaxant to the end of tracheal intubation.

A pressurized mask for assisted ventilation is commonly used during general anesthesia, which often requires the cooperation of two anesthesiologists: one is responsible for administration, and the other carries out the assisted ventilation. However, there is currently a severe shortage of anesthesiologists. According to the 2015 data of the National Health Commission, only 0.5 anesthesiologists per 10,000 people are available in China, which is well below the standard of 2.5 anesthesiologists per 10,000 people in Western countries[3]. Because the use of a pressurized mask for assisted ventilation requires two anesthesiologists, the workload of the available anesthesiologists is markedly increased. Moreover, the pressurized mask must be placed on the patient in advance. However, the patient still experiences slight confusion before the muscle relaxant is fully effective. Actions such as chin lift maneuvers lift may increase the patient’s sense of fear and discomfort, even provoking resistant behaviors, which reduces the effect of ventilation and violates the principle of humanistic care. Notably, pressurized mask-assisted ventilation may also increase the peak inspiratory pressure, increasing the risks of gastric insufflation and reflux aspiration[4-6].

High-flow nasal cannula oxygenation (HFNCO) is a novel oxygenation technology mainly involving the use of an air–oxygen mixer, a flow regulator, a humidifier, and a heated breathing circuit. It provides an oxygen flow rate of up to 70 L/min and heats and humidifies the gas[7, 8]. It also improves patient oxygenation and reduces anatomical dead space and the work of breathing while generating positive airway pressure[9]. Dewan and Bell[10] first applied this method for patients with chronic obstructive pulmonary disease about 20 years ago. It is now widely used in respiratory medicine and intensive care units for the treatment of acute respiratory failure[11, 12] and for improved aerosol therapy and bronchoscopy[9, 13]. However, its application in the induction of general anesthesia has been rarely reported, and its safety and efficacy need to be verified further.

In the present study, we used the Airvo™ 2 high-flow nasal cannula oxygenator (Fisher & Paykel Healthcare Limited, Auckland, New Zealand) for general anesthesia. During induction, we used this device only for oxygen inhalation without assisted ventilation. We expect the application of HFNCO to reduce clinicians' workload and relieve the pressure due to the shortage of anesthesiologists. Thus, the present study was performed to explore the safety and effectiveness of HFNCO for general anesthesia induction by direct providers and provide a basis for the use of HFNCO in clinical anesthesia.

Methods

Twelve patients who underwent elective surgery under general anesthesia in Xi'an People's Hospital (Xi'an Fourth Hospital) from September 2021 to December 2021 were enrolled in this study. After entering the operating room, the patients underwent routine monitoring of their electrocardiogram, noninvasive or invasive blood pressure, and pulse oxygen saturation. Arterial blood was then collected for blood gas analysis, and preoperative oxygenation was detected. The initial oxygen flow was set to 30 L/min at 37°C and the oxygen concentration was set at 100%. The duration of inhalation was about 3 to 5 minutes. The second arterial blood gas analysis was conducted after oxygen inhalation. High-flow nasal cannula oxygen inhalation was continued during anesthetic induction, and the oxygen flow was increased to 65 L/min after the onset of muscle relaxants without assisted ventilation during this period. Tracheal intubation was performed after peak efficacy of the muscle relaxant was obtained, and appropriate parameters were set for mechanical ventilation. The third arterial blood gas analysis was conducted to evaluate the patient's oxygenation and CO_2 accumulation during apnea oxygenation. Only one qualified anesthesiologist participated during general anesthesia, and the anesthesia nurses helped collect arterial blood for the blood gas analyses. The patient's blood pressure, heart rate (HR), and oxygen saturation were also recorded. If the patient developed severe hypoxemia (SpO_2 of <90%) during induction, the anesthesiologist immediately initiated pressurized mask-assisted ventilation and complete tracheal intubation.

All the data were sorted, summarized in Excel, analyzed statistically using SPSS software, and presented as mean ± standard deviation.

Results

This case series included 12 patients (5 men and 7 women) scheduled for elective surgery under general anesthesia. The patients' mean age was 53±10 years, and their mean body mass index was 25.5±2.7 kg/m^2. The patients' mean preoperative HR was 78±14 beats/min, and their mean arterial pressure was about 98±11 mmHg. The American Society of Anesthesiologists grade was II in 10 patients and III in 2 patients. The modified Mallampati score was I in four patients and II in eight patients (Table 1).

Table 1. Baseline Patient Characteristics

Number of patient: n=12		
Gender		
	Male	5 (42%)
	Female	7 (58%)
Age; years		53±10
Height; cm		161±5
Weight; kg		66±6
BMI; kg/m^2		25.5±2.7
Heart rate;bpm		78±14
Mean arterial pressure; mmHg		98±11
ASA status		
	II	10
	III	2
Modified Mallampati score		
	I	4
	II	8
Cormacke-Lehane score		

I	3
II	9

Data are presented as n (%) or mean ± standard deviation. BMI, body mass index; ASA, American Society of Anesthesiologists.

Among the 12 patients, only 1 was switched to pressurized mask-assisted ventilation and successfully intubated because of severe hypoxemia during apnea oxygenation (SpO_2 of 82%). The remaining 11 patients completed the induction of anesthesia under HFNCO, with a mean apnea time of 3±1 minutes.

Next, we recorded the patients' blood pressure and HR before surgery (T_0) as the baseline and measured the mean arterial pressure before pre-oxygenation (T_1), during anesthesia (T_2), and before mechanical ventilation (T_3). The mean arterial pressure before mechanical ventilation (T_3) was significantly lower than that before surgery (T_0) (Fig. 1A), which might have been caused by the anesthetics. Consequently, the HR did not change significantly (Fig. 1B).

We also collected the patients' arterial blood for blood gas analysis, and the pH, PaO_2, and $PaCO_2$ were analyzed. The data showed that the mean PaO_2 before pre-oxygenation (T_1), during anesthesia (T_2), and before mechanical ventilation (T_3) was 86.6±26.0, 245.3±90.6, and 170.0±99.4 mmHg, respectively (Fig. 1C). The lowest SpO_2 value was 92% (Fig. 1D) before mechanical ventilation (T_3), and the $PaCO_2$ values were 39.0±6.2, 40.0±5.7, and 50.2±8.7 mmHg, respectively. The lowest and highest $PaCO_2$ values at T_3 were 39.5 and 71.1 mmHg, respectively (Fig. 1E). The mean pH values were 7.40 ±0.02, 7.39±0.05, and 7.35±0.06, respectively (Fig. 1F).

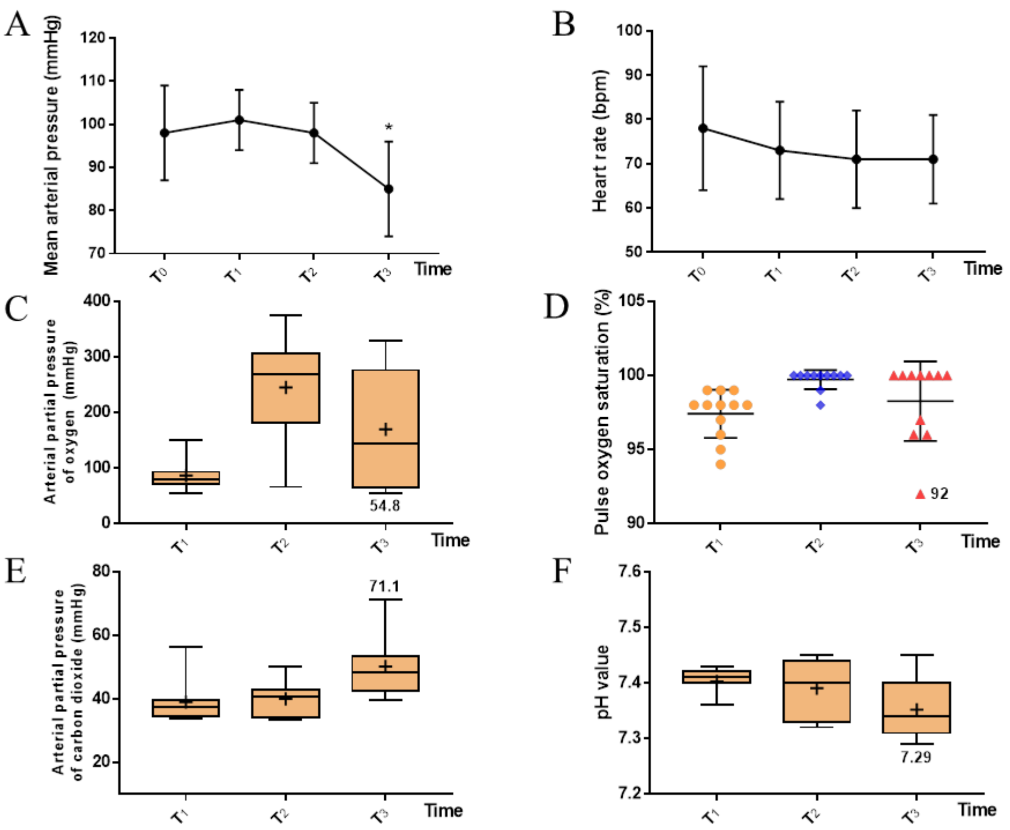

Figure 1. Comparison of vital signs among different time points. The (A) mean arterial pressure, (B) heart rate, (C) arterial partial pressure of oxygen, (D) pulse oxygen saturation, (E) arterial partial pressure of carbon dioxide, and (F) pH were recorded. Data are presented as mean ± standard deviation. *$P<0.05$ *vs*. T_0. The box plots show the median, first, and third quartiles.

Discussion

The current findings show that the application of HFNCO significantly improves the patient’s oxygenation level, helping to maintain stable vital signs without severe hypercapnia during induction of general anesthesia. Additionally, the safety of HFNCO was confirmed during induction of general anesthesia by direct providers.

In recent years, anesthesiology has transformed from a simple clinical to a comprehensive discipline comprising clinical anesthesia, pain diagnosis and treatment, and critical care management, showing gradual development in the direction of perioperative medicine[14-16]. The current scope of anesthesiologists’ role includes the preoperative, intraoperative, and postoperative condition of surgical patients. Moreover, the continuous development of the concept of comfortable medical treatment has led to an increasing shortage of anesthesiologists. The current standard for induction of general anesthesia involves pressurized mask-assisted ventilation for denitrogenation and oxygenation, which increases the time of asphyxiation. Therefore, two anesthesiologists are required to complete endotracheal intubation during the induction of general anesthesia (one for administration and one for pressurized mask-assisted ventilation), leading to a severe shortage of anesthesiologists in the clinical setting.

HFNCO is gradually becoming favored by anesthesiologists because of its convenience and ability to provide high-flow oxygen. The device can provide an oxygen flow rate of 60 L/min, and the inspired oxygen concentration can be adjusted up to 100% by the oxygen flowmeter. The high-flow oxygen flushing reduces the anatomical dead space and facilitates alveolar expansion[17]. Moreover, when the oxygen flow rate reaches 50 L/min, positive airway pressure of about 3.31±1.05 cmH_2O can be generated under closed-mouth breathing. This positive airway pressure shows an upward trend with increased oxygen flow, irrespective of open- or closed-mouth breathing[18]. This effect can improve the end-expiratory lung impedance in patients with obesity[8, 19, 20]. The heated and humidified gas provided by the device reduces the body's energy consumption for heating and humidifying the gas and improves the ability of the respiratory tract mucocilia to remove foreign bodies or sputum[21].

Based on the above advantages, HFNCO has been considered for general anesthesia induction; however, its application is limited. The use of muscle relaxants in the induction of general anesthesia makes airway management difficult. Thus, the efficacy and safety of this technology must be confirmed by large randomized controlled trials. After gaining a full understanding of the underlying principle, our center introduced the Airvo™ 2 high-flow nasal cannula oxygenator in 2021 and utilized it for single-person induction of general anesthesia. Twelve patients were enrolled in this case series. To fully ensure safety, only patients aged 18 to 65 years were enrolled and those with severe respiratory diseases before surgery were excluded. One patient's blood gas analysis report showed that the PaO_2 reached 54.8 mmHg before mechanical ventilation, indicating hypoxemia. Nonetheless, the $PaCO_2$ remained normal while the PaO_2 returned to a normal level within 5 minutes after mechanical ventilation. Interestingly, in another patient, the $PaCO_2$ increased to 71.1 mmHg and PaO_2 decreased to 62 mmHg before mechanical ventilation. After adjustment of the respiratory parameters, the patient did not have persistent severe hypercapnia or acid–base imbalance, and the hemodynamic parameters were stabilized during induction. Thus, we speculated that the abnormal blood gas analysis values of these two patients might have been caused by prolonged asphyxia (5 minutes), which could have been attributed to the occult respiratory disease before the surgery. The exact reason is unknown because of the lack of pulmonary function test data. Only 1 of the 12 patients was changed to pressurized mask-assisted ventilation because of severe hypoxemia (lowest SpO_2, 82%), which developed when the oxygen could not be delivered normally due to bending of the terminal aspect of the nasal cannula. This phenomenon prompted us to ensure that all pipelines were unobstructed and that the airway was open, although the device could improve the oxygenation. In such cases, if the cause cannot be identified in a timely manner during single-person induction, familiar airway control methods such as pressurized mask-assisted ventilation, oropharyngeal airway insertion, and nasopharyngeal tube insertion should be utilized immediately. Thus, it is important to ensure adequate oxygenation of patients.

HFNCO improves patients' oxygenation when applied during general anesthesia for short surgical procedures. It avoids severe hypercapnia, as described previously[22, 23], which is consistent with the current observations. Interestingly, no significant difference was detected in the incidence of hypoxemia, incidence of intubation complications, or length of Intensive Care Unit stay compared with mask ventilation or noninvasive ventilation when HFNCO was used for pre-anesthetic induction[24]. Because oxygenation is multifactorial, transient hypoxemia (lowest SpO_2, 72%) may occur by self-inflicted causes in some patients of advanced age[25]. Lyons and Callaghan[22] demonstrated that the average increase in end-tidal carbon dioxide was about 1.3 mmHg/min during apnea oxygenation and that the venous partial pressure of carbon dioxide was 1.6 mmHg/min in the first 15 minutes, which was much lower than our results. This might have been due to the difference in flow settings, which caused different degrees of flushing of the alveoli and alveolar ventilation. Compared with a face mask, the application of HFNCO reportedly induces prolonged safe apnea and a higher minimum SpO_2 during intubation in patients with obesity[26]. One study showed that during colonoscopy in patients with obesity, the HFNCO group achieved a higher level of oxygenation than the normal nasal cannula group[27]. This might have been a benefit of the continuous positive airway pressure, which expands the alveoli and increases the total lung volume at end-expiration. In addition, the increased inspiratory flow may reduce the work of breathing in patients with obesity. Notably, however, patients with obesity have a lower oxygen reserve, a hypertrophic tongue, and a short neck, and airway obstruction is likely to occur in the supine position, especially after the administration of muscle relaxants. The decreases in lung compliance, functional residual capacity, and lung capacity markedly reduce the efficiency of oxygen inhalation[28, 29], which is difficult to detect when anesthesia is induced by a single person and might have serious adverse consequences. Therefore, caution is needed when treating such patients.

Although the benefit of improved oxygenation by HFNCO is undoubted, the adverse effects of long-term inhalation of high-concentration or high-flow oxygen remain unknown. High concentrations of oxygen replace the nitrogen in the alveoli, leading to atelectasis[30, 31]. Another study demonstrated that HFNCO reduces the occurrence of atelectasis during postoperative long-range deep sedation compared with a mask[32]. Because of the characteristics of hypoxic pulmonary vasoconstriction in pulmonary blood vessels, shunts may increase near alveoli with low oxygen concentrations, which further aggravates the imbalance of the ventilation/blood flow ratio. For patients with type 2 respiratory failure before surgery, low-concentration oxygen inhalation might be optimal. High-concentration oxygen causes the loss of central feedback stimulated by hypoxia, thereby aggravating hypoxia; this may be a limitation of HFNCO. Notably, high concentrations of oxygen induce the development of oxidative stress, and the reactive oxygen species produced by oxygen metabolism damage the cells and even cause apoptosis[33, 34]. However, these effects have only been demonstrated at the theoretical level, and whether the concentration and duration of high-concentration oxygen inhalation will adversely affect the patient remains unknown. Additionally, assessing the pros and cons of the method is essential. The number of patients analyzed in this study is limited, and the safety of HFNCO in one-doctor induction of general anesthesia requires further verification by randomized controlled trials with large samples.

Conclusions

Overall, HFNCO could significantly improve oxygenation levels without severe hypercapnia and facilitate induction by direct providers to reduce the workload of anesthesiologists. We can screen suitable patients in whom to apply this technology and improve their oxygenation, but a high degree of caution is needed for patients with severe complications, advanced age, or obesity to ensure the safety of these patients.

List of Abbreviations

HFNCO: high-flow nasal cannula oxygenation; PaO_2: arterial partial pressure of oxygen; SpO_2: pulse oxygen saturation; $PaCO_2$: arterial partial pressure of carbon dioxide

Declarations

Ethics approval and consent to participate

All methods carried out in the study involving human participants were in accordance with Declaration of Helsinki. The anesthesia protocol used in this study was approved by the Ethics Committee of Xi'an People's Hospital (Xi'an Fourth Hospital) (Xi'an, China, Number:20200018), and all patients provided informed consent for participation and confirmed that they understood the advantages and disadvantages of the applied oxygenation technology.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and analysed during the current study are not publicly available due to protection of patient privacy and data security but are available from the corresponding author on reasonable request.

Competing interests

All authors declare that they have no conflict of interest.

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Authors' contributions

FL helped to perform the statistical analysis, review the results, and write the manuscript. FM helped to develop the questionnaire and collect the data. HC helped to perform the statistical analysis and edit the manuscript. SH helped to review the questionnaire and results and write the manuscript. All authors read and approved the final manuscript.

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