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Effect of nasal high-flow oxygen humidification on patients after cardiac surgery

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ABSTRACT

Background: Although high-flow humidified oxygen therapy (HFNC) has emerged as an important treatment for respiratory failure, few studies have reported on whether HFNC is appropriate for patients with hypoxemia after cardiac surgery, and the clinical efficacy of HFNC in patients undergoing cardiac surgery is unclear.
Objective: To investigate the clinical effect of HFNC after cardiac surgery.
Methods: Convenience sampling was used to select 76 patients who underwent invasive mechanical ventilation and oxygen therapy after valve replacement or coronary artery bypass grafting from July 2019 to June 2021. The patients were divided into the routine group and the HFNC group according to the oxygen therapy provided after the operation. The patients in the routine group (N = 38) were treated with oxygen inhalation by face mask after the operation, while those in the HFNC group (N = 38) were treated with HFNC via nasal cavity. The arterial partial pressure of oxygen (PaO_2), the arterial partial pressure of carbon dioxide ($PaCO_2$) and the oxygenation index (OI) were observed and compared between the two groups at 6 h, 12 h and 24 h after treatment. The sputum viscosity, incidence of second intubation and the intensive care unit (ICU) stay time were evaluated.
Results: The difference in $PaCO_2$ between the two groups was statistically significant at 24 h after treatment ($p < 0.05$). The PaO_2 in the HFNC group was significantly higher than in the routine group at 24 h after treatment, and the OI of the routine group was lower than in the HFNC group at 6 h, 12 h and 24 h after treatment ($p < 0.05$). The sputum viscosity in the HFNC group was better than in the routine group at 12 h and 24 h after treatment. The second intubation rate and ICU stay time in the HFNC group were lower than in the routine group ($p < 0.05$).
Conclusion: Compared with conventional mask oxygen inhalation, HFNC can effectively reduce sputum viscosity, improve oxygenation, reduce the incidence of repeated intubation and meet patients' comfort needs. It is an advantageous respiratory support strategy for patients after cardiac surgery compared with invasive mechanical ventilation to oxygen therapy and is beneficial to the recovery of cardiopulmonary function.

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1. Introduction

Pulmonary function decline, atelectasis and hypoxemia are important events after cardiac surgery [1]. According to reports, up to 50 % of patients undergoing cardiac surgery with post-extubation hypoxemia may develop pulmonary complications, such as pulmonary dilatation, pneumonia, pleural effusion or pulmonary oedema [2]. After extubation, the occurrence of pulmonary oedema, low cardiac output syndrome or other respiratory dysfunction means mechanical ventilation must be reapplied [3]. In recent years, with the continuous improvement and development of oxygen therapy technology, oxygen therapy is often used to improve the postoperative hypoxic state of patients after cardiac surgery [4].

Non-invasive oxygen therapy is one of the most important methods for treating hypoxemia. With this therapy, the flow rate of oxygen is usually less than 15 L/min, the concentration of oxygen is about 21%–50 %, the air temperature of sterilised room temperature distilled water is about 20 °C. The effect of heating and humidifying is poor, which often causes dry mouth and nose, eye discomfort, etc. and reduces the comfort and compliance of patients [5]. Conventional oxygen therapy (COT) has difficulty in meeting the oxygen demand of patients after weaning and decannulation, which affects their prognosis, with an increased risk of airway mucosa injury, abdominal distention, low tolerance and other complications [6].

In recent years, nasal high-flow humidified oxygen therapy (HFNC) has been widely used in clinical practice as a new type of ventilation. By connecting the humidifier to the nasal plug catheter, it can continuously provide high-flow, warm and humid respiratory gas without the need for closed pipes. It assists patients to breathe independently [7], which can effectively improve patient oxygenation, improve patient comfort and reduce metabolic consumption [8]. Studies have shown that HFNC can significantly improve the blood gas parameters of patients with severe coronavirus disease 2019 (COVID-19) and chronic obstructive pulmonary disease (COPD) complicated with Type 2 respiratory failure. Compared with COT, HFNC can effectively reduce the heart rate, respiratory rate and tracheal intubation rate of patients, increase the comfort of oxygen inhalation, dilute sputum, promote sputum excretion and has higher safety [9,10]. Although HFNC has emerged as an important treatment for respiratory failure, few studies have reported on whether HFNC is appropriate for patients with hypoxemia after cardiac surgery, and the clinical efficacy of HFNC in patients undergoing cardiac surgery is unclear. This cohort study was designed to observe and evaluate the effects of extubation with HFNC and COT on respiratory and syncytial indices in patients undergoing cardiac surgery, to evaluate its efficacy for HFNC patients after cardiac surgery. The sputum viscosity, intensive care unit (ICU) stay time and secondary intubation rate were measured.

2. Materials and methods

2.1. Subjects

A retrospective analysis comprising 76 patients(54 men and 22 women aged 18–78 years) who underwent invasive mechanical ventilation and oxygen therapy after valve replacement or coronary artery bypass grafting (CABG) from July 2019 to June 2021 was performed.

The inclusion criteria were: (1) age ≥18 years old, with complete clinical data; (2) standard extubation within 24 h after the operation when the indication for extubation was met according to the guide to clinical application of mechanical ventilation [11] issued by the Society of Critical Care Medicine, Chinese Medical Association, in 2006; (3) all patients underwent cardiac surgery and were admitted to cardiac ICU after the operation; (4) patients were conscious and could independently answer the doctor's questions; and (5) the oxygenation index (OI) was <300 mmHg.

The exclusion criteria were: (1) non-first-time cardiac surgery, or a combination of other surgeries and aortic dissection; (2) infection or other major organ diseases existed before the operation; (3) patients with cardiac arrest, haemodynamics instability, increased intracranial pressure or pulmonary organic lesions requiring emergency intubation for invasive mechanical ventilation; or (4) serious nasal obstruction, nasal septum defect or nasal trauma.

2.2. Study methodology

2.2.1. Experimental group

All patients received postoperative routine treatment, including antibiotics, antishock, fluid replacement, nutritional support, and maintenance of haemodynamics stability. Extubation was performed after the indication for extubation was met. Pressure support mode was used to transition the patients who met the extubation standard before extubation. The patients were divided into two groups according to the different oxygen therapy methods: the routine group (N = 38) were given oxygen by face mask after operation, and the HFNC group (N = 38) were given oxygen therapy by high flow through the nose.

2.3. Indicators and methods of observation

Sputum viscosity, arterial partial pressure of oxygen (PaO_2), arterial partial pressure of carbon dioxide ($PaCO_2$), OI and the fraction of inspired oxygen (FiO_2) were observed before and 6 h, 12 h and 24 h after oxygen therapy.

2.3.1. Evaluation of sputum viscosity

Grade I sputum: the sputum is thin and white foamy, and the patient coughs frequently; Grade II sputum: the sputum is mucus-like, with the best state of wetness, and the patient coughs easily; Grade III mucus: the sputum is white or yellow, and there is agglutination into a rapid or mass of phlegm; Grade IV degree of phlegm: yellow phlegm, and patients have difficulty coughing up sputum.

2.3.2. Standard of second intubation

(1) dyspnoea symptoms, such as dyspnoea and cyanosis of lips, were aggravated after extubation;
(2) unable to clear respiratory secretions and protect the airway within 24 h after extubation, resulting in unrelieved bronchospasm or laryngeal oedema;
(3) severe hypoxia, $PaO_2 \leq 60$ mmHg and $PaCO_2 \geq 50$ mmHg;
(4) low cardiac output.

2.4. Statistical analysis

The SPSS™ v26.0 software was used for statistical analysis. The normality test and variance homogeneity tests were performed. The mean ± standard deviation (x ± s) was used for the measurement data that obeyed the normal distribution and satisfied the homogeneity of variance, and the *t*-test was used among the groups. The χ^2 test was used for counting data. A value of $p < 0.05$ was considered significant.

3. Results

3.1. The general clinical data of the two groups were compared

There were no significant differences in gender, age, acute physiology and the Chronic Health Score II (Apache II), preoperative clinical diagnosis, preoperative ejection fraction, extracorporeal circulation time (min) and mechanical ventilation time (h) between the two groups ($p > 0.05$). This indicates there was no significant difference between the two groups, and the grouping is balanced and comparable. See Table 1.

3.2. Comparison of arterial blood gas analysis and oxygenation index between the two groups

The results showed that the PaO_2/FiO_2 ratio in the HNFC group was significantly higher than in the routine group at 6 h, 12 h and 24 h after oxygen therapy ($p < 0.05$). The $PaCO_2$ level was significantly lower at 24 h after oxygen therapy than in the routine group ($p < 0.05$). These differences were statistically significant ($p < 0.05$). See Table 2.

3.3. Comparison of sputum viscosity between the two groups

There was no significant difference in sputum viscosity between the routine group and the HFNC group before treatment ($p > 0.05$), indicating that the sputum viscosity was balanced and comparable between the two groups before oxygen therapy after weaning and extubation. There was no significant difference in sputum viscosity between the two groups at 6 h after treatment ($p > 0.05$), but the sputum viscosity in the HFNC group was better than in the routine group at 12 h and 24 h after treatment ($p < 0.05$). See Table 3.

3.4. The incidence of second intubation and intensive care unit stay time were compared between the two groups

The second intubation rate in the HFNC group was significantly lower than in the routine group ($p < 0.05$), and the mean ICU stay time was 9.605 d and 5.421 d in the routine group and the HFNC group, respectively. These differences were statistically significant ($p < 0.05$). See Table 4.

Table 1
Comparison of general data between the two groups.

Group	Case (n)	Sex Male/ Female	Age (years , ¯X ± S)	APACHE II score (years , ¯X ± S)	Preoperative diagnosis Coronary heart disease, valvular heart disease, others	Preoperative EF value	External circulation time (min)	Mechanical ventilation time (min)
Routine group	38	28 14	56.42 ± 10.87	11.74 ± 5.72	11 20 7	48 ± 12.5	70.5 ± 20.5	28.5 ± 12.5
HNFC group	38	30 8	54.97 ± 10.671	12.50 ± 5.24	3 26 9	46 ± 10.7	80.5 ± 30.6	30.5 ± 13.5
χ^2/t		2.303	0.587	−0.565	5.604	0.749	−1.673	−0.670
p value		0.129	0.559	0.574	0.061	0.462	0.103	0.511

Note: Apache II: acute physiology and Chronic Health Score II; EF: preoperative ejection fraction; HFNC: humidified oxygen therapy.

Table 2
Comparison of arterial blood gas and oxygen content index between two groups at different time points.

Group	Case (n)	6h			12h			24h		
		PaO2 (mmHg)	PaO2/FiO2	PaCO2 (mmHg)	PaO2 (mmHg)	PaO2/FiO2	PaCO2 (mmHg)	PaO2 (mmHg)	PaO2/FiO2	PaCO2 (mmHg)
Routine group	38	91.7 ± 12.6	180.1 ± 15.8	40.6 ± 10.3	94.3 ± 12.7	176.9 ± 20.3	37.1 ± 8.7	92.7 ± 10.8	174.5 ± 19.6	40.1 ± 5.8
HNFC group	38	95.5 ± 13.2	190.1 ± 16.7	39.5 ± 9.2	99.8 ± 11.3	198.8 ± 20.3	39.8 ± 10.0	105.1 ± 11.4	203.1 ± 23.4	34.1 ± 11.4
t value		−1.283	−2.681	0.490	−1.994	−4.702	−1.255	−5.024	−5.775	5.932
p value		>0.05	<0.05	>0.05	>0.05	<0.05	>0.005	<0.05	<0.05	<0.05

Note: PaO2: arterial partial pressure of oxygen; HFNC: humidified oxygen therapy; FiO2: Fraction of inspiration O2; PaCO2: partial pressure of carbon dioxide in artery.

4. Discussion

The results showed that HFNC oxygen therapy after extubation and weaning could reduce the ICU stay time, the rate of second intubation and the sputum viscosity, and the OI was significantly higher than in the conventional mask oxygen inhalation group. This indicates that HFNC is effective in improving oxygenation, reducing sputum viscosity and reducing the incidence of repeated intubation. It can meet the comfort needs of patients. It is a favourable respiratory support strategy for patients after cardiac surgery compared with invasive mechanical ventilation and is conducive to the recovery of cardiopulmonary function.

Compared with nasal catheter oxygen inhalation, mask oxygen inhalation has a larger respiratory interface area and can provide a better humidification effect. Patients with open-mouth breathing were better able to improve oxygenation, and the efficacy of mask oxygen inhalation was not affected by open-mouth breathing [12]. Oxygen inhalation through a face mask can increase the concentration of oxygen, but there are 50–100 mL of ineffective cavity in a face mask because of volume limitations, which aggravates the accumulation of carbon dioxide and leads to low actual oxygen inhalation. This affects the therapeutic effect, and it is difficult to meet patients' oxygenation needs [13].

The heart function of patients after cardiac surgery is unstable. Most patients with heart disease have different degrees of lung function changes before cardiac surgery. For patients with poor respiratory function, the maximum oxygen flow rate of 7–8 L/min is limited, and the mask is poorly sealed, resulting in air easily mixed into the pipeline, and the oxygen concentration will be affected by its airflow [14]. However, HFNC is relatively easy to use clinically and has been reported to be successfully used in the neonatal ICU [15], and in the fields of COPD with respiratory failure [16], acute cardiogenic pulmonary oedema [17], acute left heart failure [18] and sequential oxygen therapy after extubation [18], which improves the clinical prognosis.

Because HFNC technology provides an open system that connects the patient through a nasal cannula to form a respiratory interface, high-flow nasal congestion consistently provides patients with a regulated and relatively stable concentration of oxygen (21%–100 %), temperature and humidity gases [10], allowing patients to continuously breathe high-flow gases of constant temperature and humidity. Therefore, HFNC provides a better experience than mask oxygen, a smallerer direct contact surface with facial skin, continuous humidification and heating performance and a smaller nasal catheter–patient respiratory interface, which can significantly improve patient compliance and oxygen efficacy [10].

Additionally, HFNC can continuously transport oxygen flow up to 80 L/min, the flow rate can meet the oxygen demand of patients, and the OI does not change as the patient's breathing varies. This can greatly reduce the influence of indoor air on the oxygen concentration. The erosion of high-flow gas in the respiratory tube and the patient's respiratory tract can reduce the secondary absorption of carbon dioxide (CO_2), reduce the $PaCO_2$ in arterial blood, increase gas flow [19] and increase CO_2 retention. In this study, HFNC oxygen therapy was used in patients after cardiac surgery, and the OI was significantly improved compared with the traditional mask use, indicating HFNC has a significant advantage in oxygen therapy after cardiac surgery.

Through its setting of appropriate warming and humidifying functions, HFNC increases lung compliance, effectively reduces airflow resistance, promotes alveolar recruitment and reduces mucosal damage, thereby increasing oxygen therapy comfort [14]. The present study showed that the effect of HFNC treatment was better than routine treatment regarding the degree of sputum viscosity. After cardiac surgery, with routine treatment, patients were afraid to cough due to the post-operative pain, which caused the sputum to accumulate in the respiratory tract for a long time. The sputum became dry and formed a sputum suppository, which can easily lead to respiratory tract infection. Atelectasis and inspiratory issues will increase airway resistance, respiratory work and metabolic consumption, which are not conducive to prognosis. Conventional mask oxygen inhalation cannot fully meet the needs of patients regarding the humidification effect, and the respiratory mucosa is easily stimulated. The characteristics of continuous humidification of HFNC can improve the dry upper respiratory tract of patients, improve the viscosity of sputum, improve the cilia function of mucosa, promote the clearance of mucus and secretions [20] and help patients cough better. In addition, HFNC has a small respiratory interface that allows patients to eat, cough, drink and talk during treatment, which can help improve comfort and compliance. Teng et al. [21] compared HFNC humidification oxygen therapy with traditional mask airway humidification and found that humidification satisfaction was similar to the clinical results of the present study.

The present study found that HFNC can effectively reduce the rate of secondary intubation and the length of stay in the ICU [22]. Goh et al. [23] retrospectively analyzed 213 patients in the mask oxygen therapy group and 347 patients in the HFNC treatment group

Table 3
Comparison of sputum viscosity between two groups at different time points.

Group	Case (n)	Sputum viscosity before treatment (case)			6 h sputum viscosity (case)			12h sputum viscosity (case)			12h sputum viscosity (case)		
		Grade I	Grade II	Grade III	Grade I	Grade II	Grade III	Grade I	Grade II	Grade III	Grade I	Grade II	Grade III
Routine group	38	16	7	15	16	12	10	7	10	21	1	8	29
HNFC group	38	15	5	18	15	15	8	8	22	8	4	24	10
χ^2 value		0.638			0.588			10.394			19.956		
p value		0.727			0.745			0.006			0.000		

Note: HFNC: humidified oxygen therapy.

Table 4
Incidence of secondary intubation in ICU stay (d) of patients in the two groups (%).

Group	Case (n)	Secondary intubation	ICU retention time (d)
Routine group	38	14 (36.8)	9.065 ± 6.438
HNFC group	38	5 (13.16)	5.42 ± 1.154
X2/t value		5.648	3.917
p value		<0.05	<0.05

Note: ICU: intensive care unit; HFNC: humidified oxygen therapy.

who were admitted to the ICU after CABG for cardiopulmonary bypass and found results similar to the present study. Most of the patients after cardiac surgery were middle-aged and elderly patients. The effects of general anaesthesia, cardiopulmonary bypass and muscle relaxants on respiratory physiological mechanism, pain, postoperative respiratory tract infection and pre-operative underlying diseases may be the main factors of secondary tracheal intubation [24].

The humidified water in the HFNC system exists in the form of water vapor in the respiratory tract and the patient's upper respiratory tract. Water vapor is a gas formed by a single molecule, and a virus is composed of multiple molecules, meaning it is difficult for the water molecules in the steam to transport bacteria or viruses [25]. In comparison, a conventional mask will easily form water mist in the mask during the process of a patient's long-term breathing, and then gather as water droplets or drops, thus easily carrying bacteria or viruses. Therefore, the humidification mechanism of HFNC can reduce the risk of infection compared with conventional mask oxygen inhalation. The above factors may explain why HFNC reduces the rate of secondary intubation. However, the condition of patients after cardiac surgery is complicated, the postoperative complications and the time of cardiopulmonary bypass are different and multiple factors can lead to unplanned secondary intubation or a prolonged ICU stay after extubation.

This small-sample retrospective analysis preliminarily demonstrated the feasibility of oxygen therapy after extubation in patients using HFNC after cardiac surgery and has potential clinical value.

There are some limitations in the present study: (1) The sample size was small; (2) This retrospective cohort study lacked treatment for potential preoperative confounders in patients, such as differences in the type of cardiac surgery performed between the two groups; and (3) Some indicators are not fully considered, such as the lack of quantitative statistical analysis of airway humidification, comfort and other indicators.

5. Conclusion

The application of nasal high-flow oxygen inhalation in non-invasive oxygen therapy after extubation of patients after cardiac surgery is superior to conventional mask oxygen inhalation. It can effectively improve airway humidification and increase OI to reduce the incidence of unplanned second intubation.

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki and approved by the ethics committee of the First Affiliated Hospital of Gannan Medical University (No. llsc-20190306). Informed consent was obtained and signed by all patients included in the study.

Consent for publication

Not applicable.

Availability of data and materials

All data generated or analyzed during this study are included in this published article.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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