

# High frequency jet ventilation through mask contribute to oxygen therapy in patients undergoing bronchoscopic intervention under deep sedation

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## Research article

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# Abstract

**Background:** High frequency jet ventilation (HFJV) is an open ventilating technique to maintain ventilation for emergency or difficult airway. However, it is unclear whether jet ventilation or conventional oxygen therapy (COT) is more effectively and safely to maintain adequate oxygenation in patients with airway stenosis during bronchoscopic intervention (BI) under deep sedation.

**Methods:** A prospective randomized cohort study was conducted to compare HFJV with normal frequency jet ventilation (NFJV) and COT (high flow oxygen) in oxygen supplementation during BI under deep sedation from March 2020 to August 2020. Patients receiving BI under deep sedation were randomly divided into 3 parallel groups of 50 patients each: the COT group (FiO<sub>2</sub> 1.0, 12 L/min), the NFJV Group (FiO<sub>2</sub> 1.0, driving pressure 0.1MPa, respiratory rate (RR) 15bpm) and HFJV Group (FiO<sub>2</sub> 1.0, driving pressure 0.1MPa, RR 1200bpm). SpO<sub>2</sub>, MBP and HR were recorded during the whole procedure. Arterial blood gas was examined and recorded at 15 minutes after initiation of procedure. Procedure duration, dose of anesthetics and adverse events during BI in the three groups were also recorded.

**Results:** A total of 161 patients were enrolled with 11 patients excluded. Clinical characteristics were similar among the three groups. PaO<sub>2</sub> of HFJV group was significantly higher than that of COT and NFJV group ( $P<0.001$ ). PaO<sub>2</sub> was significantly correlated with ventilation mode ( $P<0.001$ ), BMI ( $P=0.019$ ) and procedure duration ( $P=0.001$ ). Multiple linear regression showed that only BMI and procedure duration were independent influencing factors of arterial blood gas PaO<sub>2</sub> ( $P=0.040$ ,  $P=0.002$ ). The location of airway lesions and severity of airway stenosis were no statistical correlation with PaCO<sub>2</sub> and PaO<sub>2</sub>.

**Conclusions:** HFJV can effectively and safely improve intra-operative PaO<sub>2</sub> in patients with airway stenosis during BI in deep sedation, and doesn't increase intra-operative PaCO<sub>2</sub> and the risk of hypercapnia. The location of airway lesions and severity of airway stenosis may not affect oxygenation maintain during basic and some advanced BI.

**Trial registration:** Chinese Clinical Trial Registry. Registration number, ChiCTR20000311110, registered on March 22, 2020.

## 1. Background

Bronchoscopic intervention (BI) has become the preferred method for the diagnosis and treatment of airway lesions. It plays an important role in improving the patient's quality of life, especially by relieving airway obstructions<sup>1</sup>. Different procedures require different methods of anesthesia and different airway management. Different oxygen delivery routes ranging from nasal catheter and face mask to laryngeal mask airway (LMA), supraglottic tube, endotracheal tube and rigid bronchoscope<sup>2,3</sup>. Endoscopic face mask is one of the most commonly used oxygen delivery route for BI because of its high comfort and no influence on bronchoscope insertion. Different ventilation modes, including conventional oxygen therapy

(COT), intermittent ventilation, controlled mechanical ventilation, and jet ventilation can be utilized for conducting differentiated airway management, which having its own advantages and disadvantages<sup>4-6</sup>.

Hypoxemia was a major complication and anesthesia focus during deep sedation especially in patients undergoing BI<sup>7,8</sup>. The main mechanisms of hypoxemia in BI were ventilation/blood flow imbalance and decreased ventilation according to airway stenosis especially after sedation. High-flow oxygen through nasal cannula or mask was used in patients with COVID-19, and it showed reductions in the need for therapeutic escalation and the need for intubation in patients who received high-flow oxygen<sup>9</sup>.

Supraglottic jet ventilation (SJV) was also superior to conventional means of oxygen delivery in obese patients under intravenous anesthesia<sup>10</sup>. However, it is unclear whether jet ventilation is superior to COT in maintaining intra-operative oxygenation in patients with airway stenosis during BI under deep sedation.

The aim of this cohort study was to assess the efficacy and safety of oxygen supplementation in three ventilation modes including COT, normal frequency jet ventilation (NFJV) and high frequency jet ventilation (HFJV) during BI under deep sedation.

## 2. Methods

### 2.1. Study design

This is a prospective randomized cohort study comparing COT, NFJV and HFJV in oxygen supplementation during BI under deep sedation.

This study was approved by the Medical Research Ethics Committee of Emergency General Hospital in Beijing, China (K20-9). All the patients or their relatives signed informed consent prior to the commencement of the study program. This study was registered in Chinese Clinical Trial Registry on March 22, 2020. Registration number was ChiCTR2000031110. This study followed the Consolidated Standards of Reporting Trials (CONSORT) guidelines.

### 2.2. Study population

All patients were selected by the center of BI, Emergency General Hospital, to undergo BI under deep sedation from March 2020 to August 2020. Inclusion criteria were as follows: (i) Underwent electric flexible bronchoscope; (ii) Duration of operation, between 20 and 60 minutes; (iii) Age, 18–80 years. The exclusion criteria were as follows: (i) Diagnosed with cardiac respiratory failure, coma; (ii) T-tube, endotracheal intubation and tracheotomy, or SpO<sub>2</sub> < 90% in the room before the surgery; (iii) History of mental and neurological disorders, sedative or hypnotic drugs and alcohol abuse; (iv) Changing the method of anesthesia during the operation; (v) Intraoperative massive hemorrhage; (vi) Patients transferred back to ICU with endotracheal intubation after operation.

BI procedures were advanced diagnostic and therapeutic procedures, which included laser, electrocautery, cryotherapy, balloon dilation, argon plasma coagulation and photo dynamic therapy. All BI procedures were performed by experienced endoscopists using electric flexible bronchoscope (Pentax, Japan).

### 2.3. Anesthetic settings and maintenance

After entering the operating room, the patient underwent electrocardiogram (ECG), pulse oximetry (SpO<sub>2</sub>) and blood pressure monitoring. Lidocaine was administered with the spray-as-you-go technique before therapy. Endoscopic face mask was provided for oxygen. Intermittent injection of remifentanyl (1ug/kg) and continuous injection (0.10–0.15ug·kg<sup>-1</sup>·min<sup>-1</sup>) was performed according to the patient's vital signs. Propofol (1 mg/kg) was injected 2minutes after remifentanyl administered, and followed by continuous infusion (30–50ug·kg<sup>-1</sup>·min<sup>-1</sup>). Patients maintained a Ramsey Sedation Scale (RSS) score of 3–4. During BI, the patients breathed spontaneously, and when the SpO<sub>2</sub> values were < 90%, the anesthesiologists would adjust the parameters of ventilator or perform mask-bag ventilation. According to different ventilation modes, eligible patients will be randomized in a 1:1:1 ratio into 3 parallel groups of 50 patients each by a physician unaware of the study. Three groups were COT Group, NFJV Group and HFJV Group. Oxygen of COT was provided using fractional inspired oxygen (FiO<sub>2</sub>) of 1.0 with a flow of 12 L/min through ventilator (Drager, Germany). Oxygen of NFJV was provided FiO<sub>2</sub> of 1.0 with driving pressure (DP) of 0.1 MPa, respiratory rate (RR) of 15 bpm and I/E ratio of 1:1.5 through jet ventilation (Twin Stream™, Austria). Oxygen of HFJV was provided FiO<sub>2</sub> of 1.0 with DP of 0.1 MPa, RR of 1200 bpm and I/E ratio of 1:1.5 through jet ventilation (Twin Stream™, Austria).

### 2.4 Data Collection

The following parameters were continuously monitored during anesthesia: pulse SpO<sub>2</sub>, mean blood pressure (MBP), heart rate (HR) and ECG. At the same time, the patients' SpO<sub>2</sub>, MBP and HR will be recorded at baseline (T<sub>0</sub>), beginning of procedure (T<sub>Beq</sub>), 15 minutes after initiation of procedure (T<sub>15</sub>), and at the end of procedure (T<sub>End</sub>). Arterial blood gas (ABG) was examined and recorded at 15 minutes after initiation of procedure. Procedure duration and dose of anesthetics during BI in the three groups were also recorded. Adverse events intra-operation and post-operation were recorded, including hypoxemia, severe hypercapnia, and post-operative agitation and so on. The location and severity of airway stenosis were recorded. The location of airway lesions was divided into four types: 1) the lesions were located in the upper and middle part of the main airway, 2) the lesions were located in the middle and lower part of the main airway, 3) the lesions were located in the left or right main bronchial, 4) the lesions were located in the distal bronchial. The severity of airway stenosis was graded to three levels: 1 for 0–59%, 2 for 60–89%, and 3 for above 90%.

## 3. Statistical Analysis

SPSS 20.0 software was used for data collation and statistical analysis. The measurement data was expressed as mean ± SD and the count data was presented as the number and percentage. The chi-square test was used to compare the counting data of different groups (The *P* value was directly calculated by Fisher's exact probability method if necessary). Univariate analysis of variance (ANOVA) was used for the overall comparison among groups, and least significance difference (LSD) was used for the multiple comparison between groups. Pearson analysis was used to investigate the correlation

between blood gas indicators of PaO<sub>2</sub> and PaCO<sub>2</sub> and clinical indicators of patients. Multiple linear regression analysis was used to explore independent influencing factors of blood gas indicators PaO<sub>2</sub> and PaCO<sub>2</sub>.  $P < 0.05$  was statistically significant.

## 4. Results

A total of 161 patients were enrolled. Three patients in the COT group, four patients in NFJV group and another four patients in HFJV group were excluded because of change to rigid bronchoscope and general anesthesia during operation. All the remaining patients tolerated the BI well. Two patients in the COT group, three patients in the NFJV group and two patients in the HFJV group developed hypoxemia, respectively. There were no other adverse events happened including severe hypercapnia and postoperative agitation.

The clinical characteristics of patients were represented in Table 1. No significant differences were found among three groups in age, height, weight, body mass index (BMI), gender, pathological type, ASA classification, lesion site and stenosis degree. There were significant differences among three groups in comorbidities: cerebrovascular disease, other tumors (including esophageal cancer, thyroid cancer, etc.), chronic lung disease (including tuberculosis pneumonia, COPD, etc.) ( $P = 0.011$ ,  $P = 0.029$ ,  $P = 0.017$ ) and no significant difference was found in the rest. The number of patients with cerebrovascular disease in the COT group was significantly higher than that in the NFJV and HFJV groups ( $P = 0.011$ ). The number of patients with other tumors (including esophageal cancer, thyroid cancer, etc) in the NFJV group was significantly higher than that in the HFJV group ( $P = 0.029$ ). The number of patients with chronic lung disease (including tuberculosis pneumonia, COPD, etc) in the COT group was significantly higher than that in the NFJV group ( $P = 0.017$ ).

**Table 1. Comparison of preoperative patient characteristics in three groups**

Characteristic	Group COT(n=50)	Group NFJV(n=50)	Group HFJV(n=50)	<i>P Value</i>
Age, mean±SD, years	49.12±14.44	54.24±15.54	51.6±14.39	0.227
Height ,mean±SD, (cm)	165.02±7.74	167.16±7.13	167.04±8.71	0.316
Weight, mean±SD, (Kg)	61.26±8.33	63.46±11	63.59±10.33	0.423
Body Mass Index, mean±SD(%)	22.60±3.38	22.66±3.37	22.74±2.71	0.976
Male, n (%)	33(66)	32(64)	34(68)	0.915
<b>ASA score</b>				0.157
Grade I, n (%)	0(0)	0(0)	2(4)	
Grade II, n (%)	20(40)	26(52)	27(54)	
Grade III, n (%)	30(60)	24(48)	21(42)	
<b>Comorbidities</b>				
Cardiovascular history, n (%)	9(18)	12(24)	11(22)	0.757
Cerebrovascular disease, n (%)	5(10) <sup>bc</sup>	0(0) <sup>a</sup>	0(0) <sup>a</sup>	<b>0.011</b>
Other tumors, n (%)	5(10)	9(18) <sup>c</sup>	1(2) <sup>b</sup>	<b>0.029</b>
Diabetes mellitus, n (%)	3(6)	6(12)	10(20)	0.108
Chronic pulmonary disease, n (%)	6(12) <sup>c</sup>	0(0) <sup>a</sup>	1(2)	<b>0.017</b>
Tracheal esophageal fistula, n (%)	1(2)	2(4)	5(10)	0.277
Lobectomy, n (%)	10(20)	6(12)	6(12)	0.426
<b>Pathology</b>				
Non-tumor, n (%)	20(40)	23(46)	18(36)	0.592
Tumor, n (%)	30(60)	27(54)	32(64)	0.592
<b>lesion location</b>				0.074
Upper main airway, n (%)	17(34)	14(28)	10(20)	
Lower main airway, n (%)	12(24)	22(44)	16(32)	
Left and right bronchus, n (%)	8(16)	10(20)	9(18)	
Others, n (%)	13(26)	4(8)	15(30)	
<b>Degree of stenosis</b>				0.837
0-59%, n (%)	28(56)	33(66)	32(64)	
60-89%, n (%)	12(24)	10(20)	9(18)	
≥90%, n (%)	10(20)	7(14)	9(18)	

Data were expressed as mean ± standard deviation or as numbers and percentages. <sup>a</sup> was statistically significant compared with COT group, <sup>b</sup> was statistically significant compared with HFJV group, <sup>c</sup> was statistically significant compared with NFJV group.

The number of patients with cerebrovascular disease in the COT group was significantly higher than that in the NFJV and HFJV groups ( $P=0.011$ ). The number of patients with other tumors (including esophageal cancer, thyroid cancer, etc) in the NFJV group was significantly higher than that in the HFJV group ( $P=0.029$ ). The number of patients with chronic lung disease (including tuberculosis pneumonia, COPD, etc) in the COT group was significantly higher than that in the NFJV group ( $P=0.017$ ).

COT, conventional oxygen therapy; NFJV, normal frequency jet ventilation; HFJV, high frequency jet ventilation.

Data of the blood gas values and procedure duration were analyzed in Table 2. PaO<sub>2</sub>, lactic acid and procedure duration were significantly different among the three groups ( $P < 0.001$ ,  $P = 0.005$ ,  $P = 0.038$ , respectively). Compared with the COT and NFJV group, PaO<sub>2</sub> in HFJV group significantly increased from 176.28 mmHg to 251.7 mmHg. Moreover, and lactic acid of HFJV group was significantly higher and procedure duration was significantly longer than that in COT group. There were no significant differences in PaCO<sub>2</sub>, blood glucose and pondus hydrogenii (PH) among three groups ( $P = 0.972$ ,  $P = 0.203$ ,  $P = 0.647$ , respectively).

**Table 2 Blood gas values and procedure duration in three groups**

Patients values	Group COT(n=50)	Group NFJV(n=50)	Group HFJV(n=50)	P Value
PaO <sub>2</sub> (mmHg)	176.28±73.38 <sup>b</sup>	191.98±88.38 <sup>b</sup>	251.70±86.63 <sup>ac</sup>	<b>&lt;0.001</b>
PaCO <sub>2</sub> (mmHg)	59.20±15.23	59.84±14.1	59.60±10.69	0.972
Pondus hydrogenii	7.32±0.07	7.31±0.06	7.31±0.06	0.647
Glucose (mmol/l)	6.36±1.77	6.88±1.91	7.01±2.06	0.203
Lactic acid(mmol/l)	1.07±0.42 <sup>b</sup>	1.36±0.65	1.58±1.07 <sup>a</sup>	<b>0.005</b>
Procedure duration (min)	27.90±8.75 <sup>b</sup>	29.30±8.51	33.00±12.74 <sup>a</sup>	<b>0.038</b>

\*Data were presented as mean± standard deviation (median, range). <sup>a</sup> was statistically significant compared with COT group, <sup>b</sup> was statistically significant compared with HFJV group, <sup>c</sup> was statistically significant compared with NFJV group.

There were significant differences among the three groups in PaO<sub>2</sub>, lactic acid and procedure duration ( $P<0.001$ ,  $P=0.005$ ,  $P=0.038$ ). Moreover, PaO<sub>2</sub> of HFJV group was significantly higher than that of COT and NFJV group.

Lactic acid and procedure duration of HFJV group was significantly higher than that of COT group.

COT, conventional oxygen therapy; NFJV, normal frequency jet ventilation; HFJV, high frequency jet ventilation.

MAP, HR, SpO<sub>2</sub> of each period time and anesthetic doses among three groups were not significantly different and showed in Fig. 1 and Fig. 2, respectively.

All peri-operative related factors were detected by Pearson analysis associated on PaO<sub>2</sub>. The result showed that PaO<sub>2</sub> was significantly correlated with ventilation mode ( $P<0.001$ ), BMI ( $P=0.019$ ) and procedure duration ( $P=0.001$ ). The ASA level, location of airway lesions and severity of airway stenosis were no statistical correlation with PaO<sub>2</sub> ( $P=0.143$ ,  $P=0.092$ ;  $P=0.101$ ). Multiple linear regression showed that only BMI and procedure duration are independent influencing factors of arterial blood gas PaO<sub>2</sub> ( $P=0.040$ ,  $P=0.002$ ), and ventilation mode was not the independent factor of arterial blood gas PaO<sub>2</sub> ( $P=0.447$ ). The details were represented in Table 3 and Table 4.

**Table3 Pearson analysis of blood gas PaO<sub>2</sub> related factors**

Characteristic	F	P
Group COT/NFJV/HFJV	11.474	<b>&lt;0.001</b>
Body mass index	-0.191	<b>0.019</b>
Procedure duration	0.270	<b>0.001</b>
ASA score	1.971	0.143
Lesion location	2.187	0.092
Degree of stenosis	2.328	0.101

Pearson analysis showed that PaO<sub>2</sub> was significantly correlated with ventilation mode, body mass index and procedure duration.

COT, conventional oxygen therapy; NFJV, normal frequency jet ventilation; HFJV, high frequency jet ventilation.

Lesions location: 1) the upper and middle part of the main airway, 2) the middle and lower part of the main airway, 3) the left or right main bronchial and 4) in the distal bronchial. Degree of stenosis: 1 for 0-59%, 2 for 60-89%, and 3 for above 90%.

**Table4 Multiple linear regression analysis of blood gas PaO<sub>2</sub> related factors**

Variables	Regression coefficient	95% Confidence interval	P Value
Body mass index	-4.607	(-9.000, -0.215)	<b>0.040</b>
Procedure duration	2.133	(0.794, 3.472)	<b>0.002</b>
Group COT/NFJV/HFJV	6.489	(-10.315, 23.294)	0.447

Multiple linear regression results showed that body mass index and procedure duration were independent influencing factors of blood gas PaO<sub>2</sub> respectively.

COT, conventional oxygen therapy, NFJV: normal frequency jet ventilation; HFJV, high frequency jet ventilation.

All the factors were also detected by Pearson analysis associated on PaCO<sub>2</sub>, showed in Table 5. It showed that there was no statistical correlation between blood gas PaCO<sub>2</sub> and ventilation mode, lesion location, stenosis degree, and procedure duration. The above indexes are not independent influencing factors of blood gas PaCO<sub>2</sub> detected by multiple linear regression, showed in Table 6. The location of airway lesions and severity of airway stenosis were no statistical correlation with PaCO<sub>2</sub> ( $P = 0.714$ ,  $P = 0.194$ ).

**Table5 Pearson analysis of blood gas PaCO<sub>2</sub> related factors**

Characteristic	F	P
Group COT/NFJV/HFJV	0.029	0.972
Body mass index	0.077	0.351
Procedure duration	0.043	0.601
ASA score	0.486	0.616
Lesion location	0.239	0.869
Degree of stenosis	0.714	0.491

Pearson analysis showed that there was no statistical correlation between blood gas PaCO<sub>2</sub> and ventilation mode, ASA classification, lesion location, stenosis degree, body mass index and procedure duration.

COT, conventional oxygen therapy; NFJV, normal frequency jet ventilation; HFJV, high frequency jet ventilation; Lesions location: 1) the upper and middle part of the main airway, 2) the middle and lower part of the main airway, 3) the left or right main bronchial and 4) in the distal bronchial. Degree of stenosis: 1 for 0-59%, 2 for 60-89%, and 3 for above 90%.

**Table6 Multiple linear regression analysis of blood gas PaCO<sub>2</sub> related factors**

Variables	Regression coefficient	95% Confidence interval	P Value
Body mass index	0.292	(-0.429, 1.012)	0.425
Procedure duration	0.085	(-0.131, 0.301)	0.438
Group COT/NFJV/HFJV	0.164	(-2.554, 2.883)	0.905
Lesion location	-0.398	(-2.540, 1.744)	0.714
Degree of stenosis	-1.960	(-4.929,1.009)	0.194

The above indexes are not independent influencing factors of blood gas PaCO<sub>2</sub>.

COT, conventional oxygen therapy; NFJV, normal frequency jet ventilation; HFJV, high frequency jet ventilation Lesions location: 1) the upper and middle part of the main airway, 2) the middle and lower part of the main airway, 3) the left or right main bronchial and 4) in the distal bronchial. Degree of stenosis: 1 for 0-59%, 2 for 60-89%, and 3 for above 90%.

## 5. Discussion

In recent years BI has been a growing pulmonary medicine in diagnostic and therapeutic with remarkable advancements. Different airway treatments are supplemented by different anesthesia methods ranging from conscious sedation to general anesthesia. Monitored anesthesia care (MAC) as moderate sedation was performed in basic and some advanced bronchoscope procedures<sup>11</sup>. By maintaining spontaneous breathing, without the need for LMA or intubation, MAC can meet surgical needs and alleviates the patient's discomfort<sup>1</sup>. The key of MAC in BI is how to maintain the patient's oxygenation in the open airway and ensure the feasibility of procedures meanwhile. Commonly used ventilation modes included COT, intermittent ventilation, controlled mechanical ventilation, and jet ventilation (manual or automatic, high or normal frequency)<sup>11, 12</sup>. Ventilation mode is the most direct factor affecting oxygenation of patients, especially in MAC<sup>6, 13</sup>. At present, common ventilation routes included nasal catheter, face mask, superior glottis airway tools, endotracheal tube, and tracheotomy tube. In this study, endoscopic face mask and three ventilation modes were used to provide oxygen for patients<sup>14</sup>.

HFJV became a technique to maintain ventilation since Klain and Smith developed it<sup>5, 6</sup>. Gas enters the breathing path at low pressure through a narrow jet tube. Open system, high frequency and low tide are the three characteristics of HFJV. It has become one of the most important ventilation modes in airway management, especially in emergency airway in the ASA guide<sup>7</sup>. This study was decided to compare the effect of oxygenation maintenance in COT, NFJV and HFJV via face mask during BI under MAC. PaO<sub>2</sub> of HFJV was increased to 251.70 mmHg, far more than that in COT and NFJV group. It indicated that HFJV improved intra-operative PaO<sub>2</sub> compared with COT and NFJV. HFJV had a certain PEEP effect, which can open the airway, reduce the anatomical inefficiency of the nasopharyngeal cavity, improve the final expiratory volume of the lung, and increase the effective ventilation of the alveoli<sup>15, 16</sup>. It also provided a higher frequency and improved ventilation especially in patients with airway stenosis. The PaO<sub>2</sub> in NFJV was 191.98 mmHg, higher than that in COT group (176.28 mmHg), but there was no statistical difference. The mechanism of NFJV was similar with HFJV. NFJV may cause asynchronous breathing, resulting in less significant oxygenation improvement than HFJV.

In addition to the PaO<sub>2</sub>, another point of concern is the patient's PaCO<sub>2</sub>. Previous review proved that NFJV was more suitable for BI compared with HFJV, which may cause carbon dioxide accumulation caused when jet frequency above 150/min<sup>17</sup>. The PaCO<sub>2</sub> in COT group, NFJV group and HFJV group was 59.20 mmHg, 59.84 mmHg and 59.60 mmHg respectively and there were no significant difference between them. Although the value of PaCO<sub>2</sub> was higher than the upper limit of normal value, there were no serious postoperative complications. Pearson analysis showed that there were no important factors affecting PaCO<sub>2</sub>, certainly no independent factors either. It had been reported that mild hypercapnia may not cause brain injury and worsen the brain's condition only when PaCO<sub>2</sub> was above 100mmHg<sup>8, 18, 19</sup>. This is the reason why anesthesiologists didn't do any treatment when PaCO<sub>2</sub> was a little above 50 mmHg.

There were three major characteristics of airway stenosis patients in this study, which were diseases, openness and ventilation. Pathological airways often caused restricted ventilation dysfunction, resulting in decreased respiratory power, increased elastic resistance, decreased alveolar compliance, and limited lung expansion, which were important factors affecting PaO<sub>2</sub><sup>4</sup>. At the same time, the extent and location of the lesions, as well as whether the open airway will aggravate its effect on PaO<sub>2</sub>, is a problem worth thinking about. The location of airway lesions was divided into four types and the severity of airway stenosis was graded to three levels. The location of airway lesions and severity of airway stenosis were imaged to be the important factors related to PaO<sub>2</sub>. While, Pearson analysis showed that location of airway lesions and severity of airway stenosis were not important factors affecting PaO<sub>2</sub>, certainly not independent factors.

In this research, the incidence of adverse events was lower than previous reported<sup>10,20</sup>. Among the 150 patients, only 7 patients developed intra-operative hypoxemia, which was relatively short and the oxygenation was effectively improved after treatment. Hypoxemia occurred mainly at two stages, one was after induction of anesthesia, and the other was in the period of balloon dilation. Rapid anesthesia induction may result in a severe reduction in the number of breaths, a severe reduction in tidal volume, and even apnea. SpO<sub>2</sub> can be effectively improved to normal after the anesthesiologist reduced the deep of anesthesia to restore the patient to spontaneous breathing or assisted bag-mask ventilation. Balloon dilatation resulted in transient complete airway obstruction. After balloon dilatation, the patient returned to normal ventilation and SpO<sub>2</sub> returned to normal quickly<sup>21,22</sup>.

There were many deficiencies in this study that deserve further research. 1. The dose and speed of the anesthetics administered during MAC determined the depth of anesthesia and degree of respiratory depression which determined PaO<sub>2</sub> directly. There was no statistically significant difference in anesthetic doses among the three groups. But PaO<sub>2</sub> may still be affected due to different patients' conditions and different operating habitus of anesthesiologists. 2. The ABG collection time was set at 15 min after the operation, when the patient was basically in a stable state of anesthesia. At this time, most obstruction of patient's airway had been treated. 3. Only the sedation score of 3–4 was recorded, the depth of anesthesia was not recorded, which was insufficient for this study.

## 6. Conclusion

HFJV through endoscopic face mask can effectively and safely improve intra-operative PaO<sub>2</sub> in patients with airway stenosis during BI in deep sedation. BMI and procedure duration are independent influencing factors of arterial blood gas PaO<sub>2</sub>. All the preoperative factors are not independent influencing factors of blood gas PaCO<sub>2</sub>. The location and severity of airway stenosis don't affect oxygenation maintain and CO<sub>2</sub> exhalation during basic and some advanced BI.

## Abbreviations

COT: conventional oxygen therapy; NFJV: normal frequency jet ventilation; HFJV: high frequency jet ventilation; BI: bronchoscopic intervention; RR: respiratory rate; LMA: laryngeal mask airway; SJV: supraglottic jet ventilation; ECG: electrocardiogram; SpO<sub>2</sub>: pulse oximetry; RSS: Ramsey Sedation Scale; FiO<sub>2</sub>: fractional inspired oxygen; DP: driving pressure; MBP: mean blood pressure; HR: heart rate; ABG: Arterial blood gas; ANOVA: univariate analysis of variance; LSD: least significance difference; BMI: body mass index; MAC: monitored anesthesia care

## Declarations

### Ethics approval and consent to participate

This study was approved by the Medical Research Ethics Committee of Emergency General Hospital in Beijing, China (K20-9). All the patients or their relatives signed informed consent prior to the commencement of the study program.

### Consent for publication

Not applicable.

### Availability of data and materials

The data sets used and/or analyzed during the current study are available from the corresponding author.

### Competing interests

All authors have no potential competing interests to declare.

### Funding

The authors declare that they have no funding.

### Authors' contributions

Study conception: HW, YZ, QC. Study design: MY, LL, HW, QC. Study conduct: MY, BW, QH, NL, YZ. Data analysis: MY. Data interpretation: MY, YZ, HW QC. Drafting of the manuscript: MY, QC. All authors approved the final version of the manuscript.

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Not applicable.

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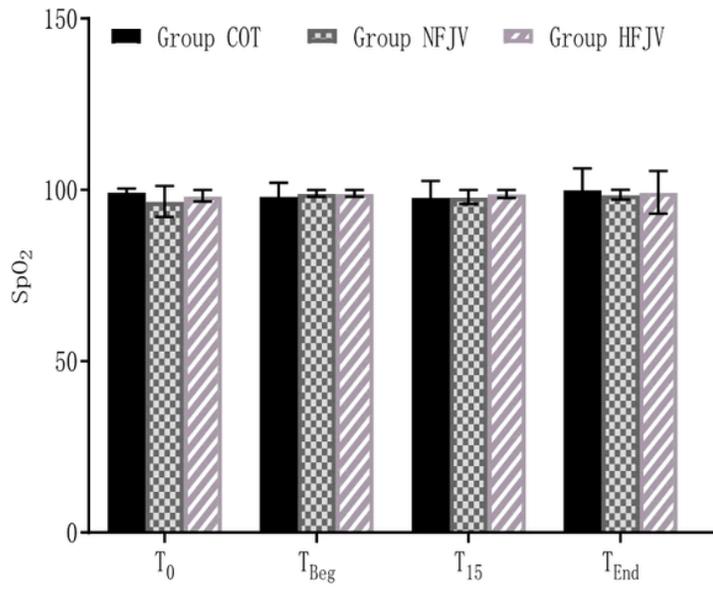
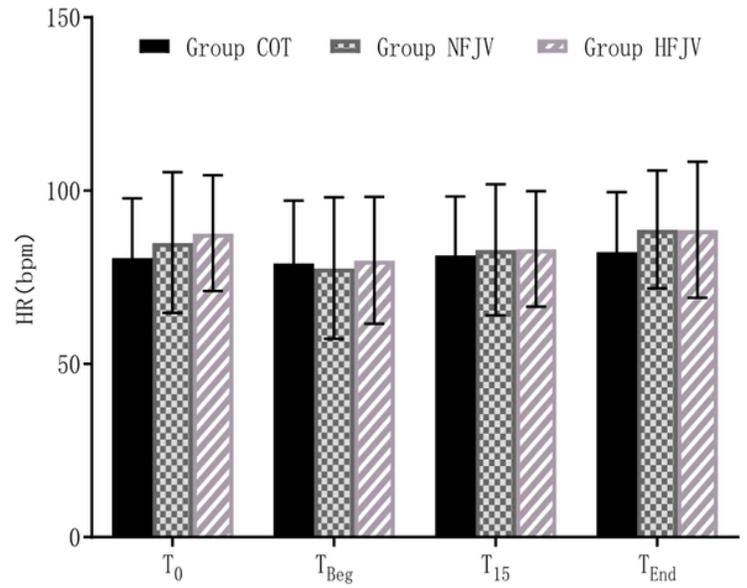
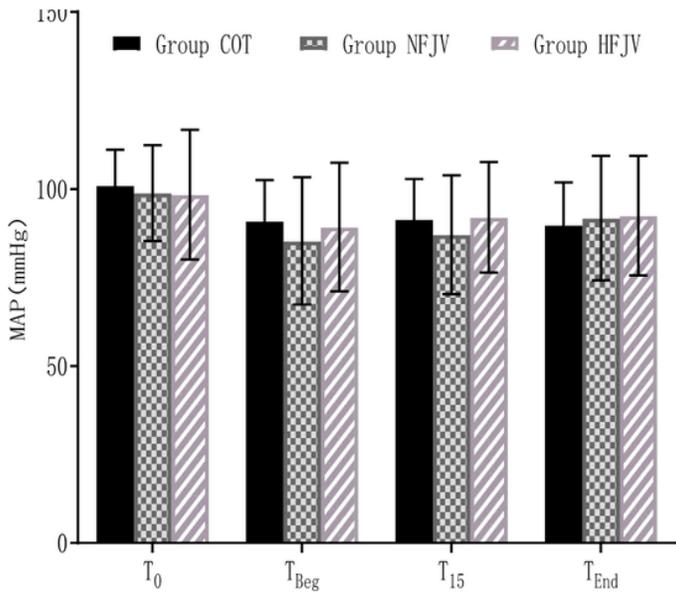
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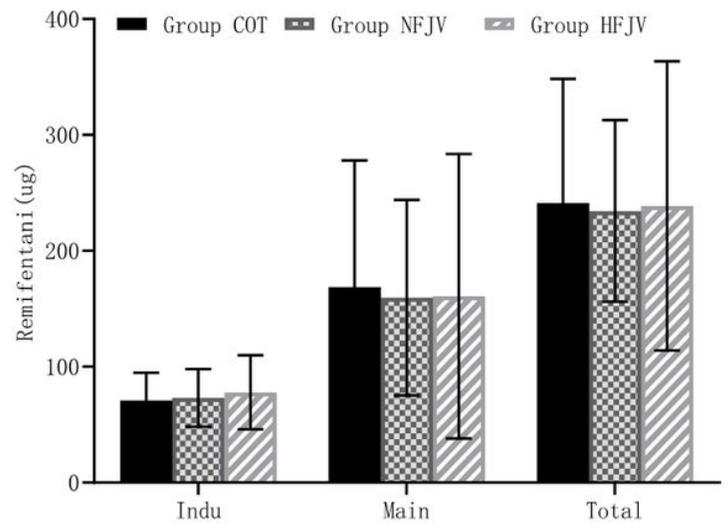
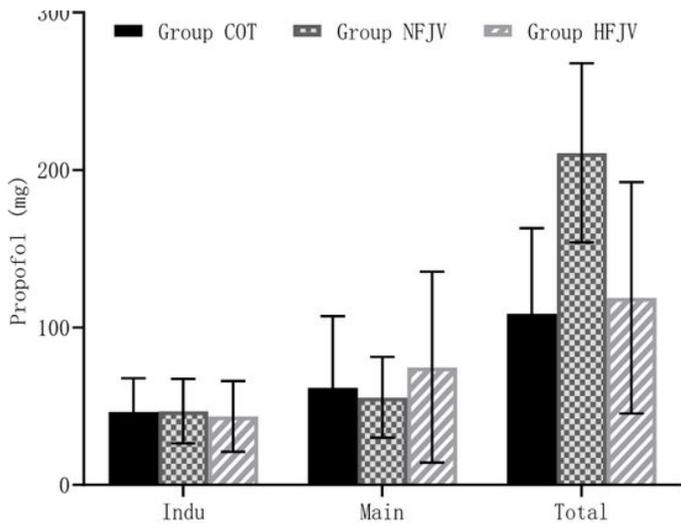
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## Figures



**Figure 1**

Hemodynamic indexes in three groups



**Figure 2**

Anesthetic doses among the three groups

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