Comparison of High-Flow Nasal Cannula and Conventional Oxygen Therapy for High Risk Patients During Bronchoscopy Examination

A Multicenter Randomized Controlled Trial

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Abstract

Rationale: Despite the increasing use of high-flow nasal cannula (HFNC) oxygen therapy during endoscopy examination, its impact on high-risk patients remains uncertain.

Objectives: We aimed to compare HFNC and conventional oxygen therapy (COT) during nasal bronchoscopy in patients at high risk for desaturation (morbid obesity, narrow trachea, or baseline hypoxemia and/or hypercapnia).

Methods: In this multicenter randomized controlled trial, patients scheduled for bronchoscopy and presenting with any high-risk factors were randomly assigned to receive HFNC or COT after providing written consent. Vital signs, pulse oximetry (Sp_{O_2}), and transcutaneous carbon dioxide were continuously monitored. The occurrence of desaturation ($Sp_{O_2} \leqslant 90\%$ lasted >10 s), frequency of examination interruption, and treatment escalation were compared between groups.

Results: Of 148 initially enrolled patients, 6 withdrew, leaving 72 and 70 in the HFNC and COT groups, respectively. Most of the patients had airway stenosis. HFNC significantly reduced desaturation occurrence during bronchoscopy (34.7% vs. 61.4%; $P = 0.016$), with fewer instances of examination interruption (26.4% vs. 58.6%; $P < 0.001$) and less frequent treatment escalation (30.6% vs. 57.1%; $P = 0.001$). During the examination, the lowest Sp_{O_2} was higher with HFNC (94% [interquartile range, 87–98%] vs. 87.5% [79–93%]; $P = 0.001$), whereas the highest transcutaneous carbon dioxide was lower (64.6 [56.8–70.1] vs. 68.3 [62.3–77.0] mm Hg; $P = 0.04$). No significant differences were observed regarding the time to the first desaturation, bronchoscopy withdrawal, durations of desaturation and bronchoscopy examination, or occurrence of other adverse events between groups.

Conclusions: In a high-risk population with predominant airway stenosis, HFNC significantly reduced desaturation occurrence, examination interruption, and treatment escalation during nasal bronchoscopy examination in high risk patients.

Clinical trial registered with www.chictr.org.cn (ChiCTR2100055038).

Keywords: bronchoscopy; high-flow nasal cannula; oxygen therapy; hypoxemia

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The high-flow nasal cannula (HFNC) system, unlike conventional oxygen therapy (COT), allows the delivery of gas flows to exceed a patient's inspiratory flow demand, thereby maintaining a relatively constant fraction of inspired oxygen ($F_{I_{O_2}}$) level within the range of 0.21–1.0 (1, 2). HFNC offers several physiological benefits for patients with pulmonary disease. These include washing out the dead space in the upper airway, improving ventilation efficiency, reducing respiratory drive and inspiratory effort, and providing a variable positive end-expiratory pressure (PEEP) (3).

Hypoxemia, a common complication during endoscopic procedures, particularly those performed under anesthesia (4–8), can range in occurrence from 29% to 90% in randomized controlled trials (RCTs) during flexible bronchoscopy examination (8–13). Several factors may contribute to hypoxemia during bronchoscopy examinations, including preexisting pulmonary diseases, increased airway resistance due to bronchoscope insertion, upper airway collapse under anesthesia, and worsened lung function due to suctioning, bleeding, or pneumothorax (14–17).

In recent years, HFNC has been increasingly used during endoscopic procedures (4–15, 18–22). Studies have demonstrated HFNC's advantages over COT in reducing hypoxemia during bronchoscopy examination (11–13, 22). However, the indiscriminate use of HFNC for all patients undergoing bronchoscopy examination may be unwarranted because of the associated high cost of supplies. In an RCT involving 788 patients undergoing bronchoscopy examinations with a mean duration of <15 minutes, fewer than one-third of patients experienced pulse oximetry saturation (Sp_{O_2}) <90% with COT (12). Thus, reserving HFNC for high-risk patients, such as those requiring extended bronchoscopy examinations, complex therapeutic interventions, or deep sedation (23), may be more cost effective (16, 24).
In addition, most previous RCTs have evaluated bronchoscopy examinations performed via the oral route (11, 13), which might compromise some benefits of HFNC, such as constant $F_{I_{O_2}}$ and PEEP, because of the patient's mouth being open throughout the procedure (25). The impact of HFNC during nasal bronchoscopy remains largely unknown. Therefore, we proposed an RCT to compare HFNC to COT during nasal bronchoscopy examination in patients with high-risk factors, hypothesizing a lower occurrence of hypoxemia in the HFNC group.

Methods

Study Design

This was a multicenter RCT conducted in three hospitals in China, which was approved by the ethics committees of the involved hospitals and registered with ChiCTR.org.cn (ChiCTR2100055038). Before participation, all patients provided written informed consent.

Study Population

Patients who had any of the following high-risk factors were eligible to participate in the study: *1*) hypoxemia with a ratio of arterial oxygen partial pressure (Pa_{O_2}) to $F_{I_{O_2}}$ ($Pa_{O_2}/F_{I_{O_2}}$) ≤ 300 mm Hg before bronchoscopy examination; *2*) hypercapnia with arterial carbon dioxide partial pressure (Pa_{CO_2}) ≥ 45 mm Hg with baseline chronic pulmonary disease, including chronic obstructive pulmonary disease, bronchiectasis, etc.; *3*) narrow trachea confirmed by radiology before bronchoscopy examination, potentially due to conditions like tracheomalacia, trachea tumor or granuloma, or aspirated foreign body, with the degree of narrowness quantified by a blinded radiologist; and *4*) morbidly obese patients with a body mass index (BMI) ≥ 30 kg/m^2. Exclusion criteria were: *1*) refusal to participate; *2*) requirement for general anesthesia bronchoscopy or rigid endoscopy; *3*) aged ≥90 years or <18 years; *4*) pregnancy; *5*) estimated bronchoscopy duration <10 minutes; *6*) contraindication to HFNC such as nasopharyngeal obstruction and blockage; *7*) oxygen requirement ≥3 L/min to maintain Sp_{O_2} at 90–97%; *8*) central airway narrowness >80%; or *9*) critical illness deemed unsuitable for study inclusion by anesthesiologists and pulmonologists.

Study Procedures

An independent statistician generated the randomization sequence, which was sealed in sequentially numbered and opaque envelopes. Eligible patients were randomly assigned 1:1 to the HFNC or COT group. HFNC (OH-70C; Micomme) was initiated at 50 L/min and increased up to 60 L/min if well tolerated. The $F_{I_{O_2}}$ was set at 0.45, with the temperature at 37°C. The size of the nasal cannula was chosen based on the patient's nasal prongs, ensuring it was smaller than 50% of the nasal prong size. Patients in the COT group received 6 L/min pure oxygen via a double-prong nasal cannula (Healthcare Medical Supplies Co.).

Before using the assigned oxygen device, anesthesia induction was administered and lasted approximately 5 minutes and sedation doses were adjusted to maintain Sp_{O_2} between 98% and 100%. Local anesthesia with lidocaine was administered before the bronchoscopy examination. During the examination, the anesthesiologist adjusted the dosage of anesthetics to maintain spontaneous breathing and a Modified Observer's Assessment of Alertness/Sedation (*see* Table E1 in the data supplement) score of 2–3 points (26). Experienced pulmonologists performed the bronchoscopy examination in the bronchoscopy suite, with continuous vital signs and Sp_{O_2} monitoring. Transcutaneous carbon dioxide (Ptc_{CO_2}) was continuously monitored using a digital system (SDMS; SenTec AG). $F_{I_{O_2}}$ for HFNC and oxygen flow for COT were maintained until the occurrence of desaturation or bronchoscopy completion.

A treatment algorithm for hypoxemia during bronchoscopy examination was implemented (27). When the patient experienced desaturation, jaw thrust maneuvers and/or interruption of the bronchoscopy examination were used to improve oxygenation. If desaturation persisted, treatment escalation was initiated: $F_{I_{O_2}}$ increased to 1.0 in the HFNC group, and COT switched to HFNC at 60 L/min with initial $F_{I_{O_2}}$ at 0.45, adjustable to 1.0 if hypoxemia persisted. Should hypoxemia continue, bronchoscopy withdrawal was the next step, and advanced airway management, including nasopharyngeal airways, oropharyngeal airways, laryngeal mask, or tracheal intubation, was considered (27). The pulmonologists determined whether to resume bronchoscopy after oxygenation recovery based on the patient's clinical condition. In addition, a designated staff member was assigned to monitor and document patients' vital signs throughout the bronchoscopy procedure. This staff member was responsible for tracking any changes in vital signs that might necessitate treatment escalation.

Bronchoscopy examination was terminated if any of the following criteria were met: *1*) occurrence of adverse events such as severe hypotension (systolic blood pressure < 90 mm Hg), severe hypertension

(systolic blood pressure > 180 mm Hg), >50% changes of blood pressure from baseline, respiratory suppression, cardiac arrest, massive bleeding, or pneumothorax; *2*) despite maximal oxygen delivery, Sp_{O_2} could not be maintained above 90%. All necessary rescue treatment and resuscitation equipment were prepared and available in the bronchoscopy suite. In the event of adverse events, patients were transferred to a general unit or intensive care unit for continuous monitoring until full recovery. After the procedure, patients were observed until their vital signs returned to prebronchoscopy status or their conditions stabilized.

Outcomes

The primary outcome was the occurrence of desaturation, defined as $Sp_{O_2} \leq 90\%$ for >10 seconds, with the number of desaturation episodes documented. Secondary outcomes included the interval between bronchoscope insertion and the first occurrence of desaturation, frequency of jaw thrust maneuvers and bronchoscopy interruptions, need for treatment escalation, lowest Sp_{O_2} and highest Ptc_{CO_2} throughout bronchoscopy examination, duration of the first desaturation and the entire examination, and occurrence of adverse events.

Sample Size Calculation

This superiority study aimed to compare the occurrence of desaturation between HFNC and COT during bronchoscopy examination. Referencing a previous study by Douglas and colleagues (10), who reported desaturation occurrences of 13.3% with HFNC and 33.3% with COT, we anticipated that the probability of desaturation would be 10% in the HFNC group and 30% in the COT group when both devices provide the similar FI_{O_2} at 0.45; the sample size was calculated to be 124 for this study, with a confidence level (α) of 95%, power (1-β) of 80%, and margin (Δ) of 0.2. Considering a 20% attrition rate, the final sample size was 148.

Statistical Analysis

Categorical variables, such as the occurrence of desaturation, treatment escalation, and bronchoscopy interruption or termination, were presented as percentages and analyzed using the chi-square test. Continuous variables, such as the desaturation duration, recovery duration, the lowest Sp_{O_2}, and the highest Ptc_{CO_2}, were presented as mean ± standard deviation or median with interquartile range. These were compared using the independent *t* test or Mann-Whitney test, based on the normality of distribution, which was determined by the Kolmogorov-Smirnov test. A two-sided $P < 0.05$ was considered statistically significant for all tests. SPSS 25.0 was used for statistical analysis, and GraphPad Prism was used to generate figures.

Results

From September 30, 2022 to June 20, 2023, 1,902 patients underwent bronchoscopy examinations. Among these, 148 patients were enrolled and randomized equally into the HFNC and COT groups. During the study period, 2 patients from the HFNC group and 4 from the COT group dropped out, yielding 72 and 70 patients, respectively, in the per-protocol analysis (Figure 1).

Patient Baseline Characteristics

Baseline characteristics of both groups at enrollment are presented in Table 1, showing no significant differences. Most enrolled patients had tracheobronchial stenosis and underwent therapeutic bronchoscopy examinations.

Anesthesia before and during Bronchoscopy Examination

There were no significant differences in anesthesia induction medications between groups. Anesthesia masks were the preferred preoxygenation method for most patients in the COT and HFNC groups (71.4% vs. 80.6%; $P = 0.203$), with similar oxygen flow (approximately 6 L/min) and preoxygenation duration (average, approximately 8 min). The changes in vital signs during the anesthesia induction were also similar (Figure 2). After anesthesia induction, patients were randomized to receive HFNC or COT. No significant differences were found in anesthesia medication dosage, cough reflex, and Modified Observer's Assessment of Alertness/Sedation scores during bronchoscopy examination (Table 2).

Primary Outcome and Management of Hypoxemia

In the COT group, 43 (61.4%) patients experienced desaturation events compared with 25 (34.7%) patients in the HFNC group ($P = 0.016$) (Table 2). Of those experiencing hypoxemia, 33 patients in the COT group had a single episode, whereas 9 had two episodes, and 1 had three episodes. In contrast, 19 patients in the HFNC group had one episode of hypoxemia, 5 had two, and 1 had three episodes.

For the 43 patients who desaturated in the COT group, jaw thrust maneuvers and bronchoscopy interruption ($n = 41$) or jaw thrust maneuvers alone ($n = 2$) improved oxygenation in only 3 patients (Figure 1). A switch to HFNC at 60 L/min and FI_{O_2} of 0.45 enhanced oxygenation in 14 out of 40 patients, whereas increasing FI_{O_2} to 1.0 was effective for 15 of the 26 remaining patients. Finally, bronchoscopy withdrawal improved oxygenation in 9 of 11 patients, with 2 still requiring advanced airway management. In comparison, for the 25 patients who desaturated in the HFNC group, jaw thrust maneuvers and/or bronchoscopy interruption improved oxygenation in 3 patients. Escalating FI_{O_2} to 1.0 improved oxygenation in 15 out of 22 patients, and withdrawing bronchoscopy benefited all 7 patients who required it.

Secondary Outcome

No significant differences were observed between groups regarding the interval from bronchoscope insertion to the first occurrence of desaturation, the duration of the first desaturation and the entire examination, and vital signs throughout the examination (Table 3). However, patients in the COT group required more jaw thrust maneuvers (61.4% vs. 33.3%; $P = 0.001$), bronchoscopy interruptions (58.6% vs. 26.4%; $P < 0.001$), and treatment escalation to maintain oxygenation during bronchoscopy examination (57.1% vs. 30.6%; $P = 0.001$). The need for HFNC at maximum settings, with flow of 60 L/min and FI_{O_2} of 1.0, was similar between groups (37.1% vs. 30.6%; $P = 0.26$). Even at maximum HFNC settings, 11 patients (15.7%) in the COT group and 7 patients (9.7%) in the HFNC group still could not maintain oxygenation and required bronchoscopy withdrawal ($P = 0.28$). During bronchoscopy examination, the lowest Sp_{O_2} was higher with HFNC (94% [interquartile range, 87–98%] vs. 87.5% [79–93%]; $P = 0.001$), whereas the highest Ptc_{CO_2} was lower (64.6 [56.8–70.1] vs. 68.3 [62.3–77.0] mm Hg; $P = 0.04$) (Figure 2). In addition, only two patients (2.8%) in the HFNC group experienced hypotension, whereas in the COT group, four patients (5.7%) had hypotension and one (1.4%) had respiratory suppression.

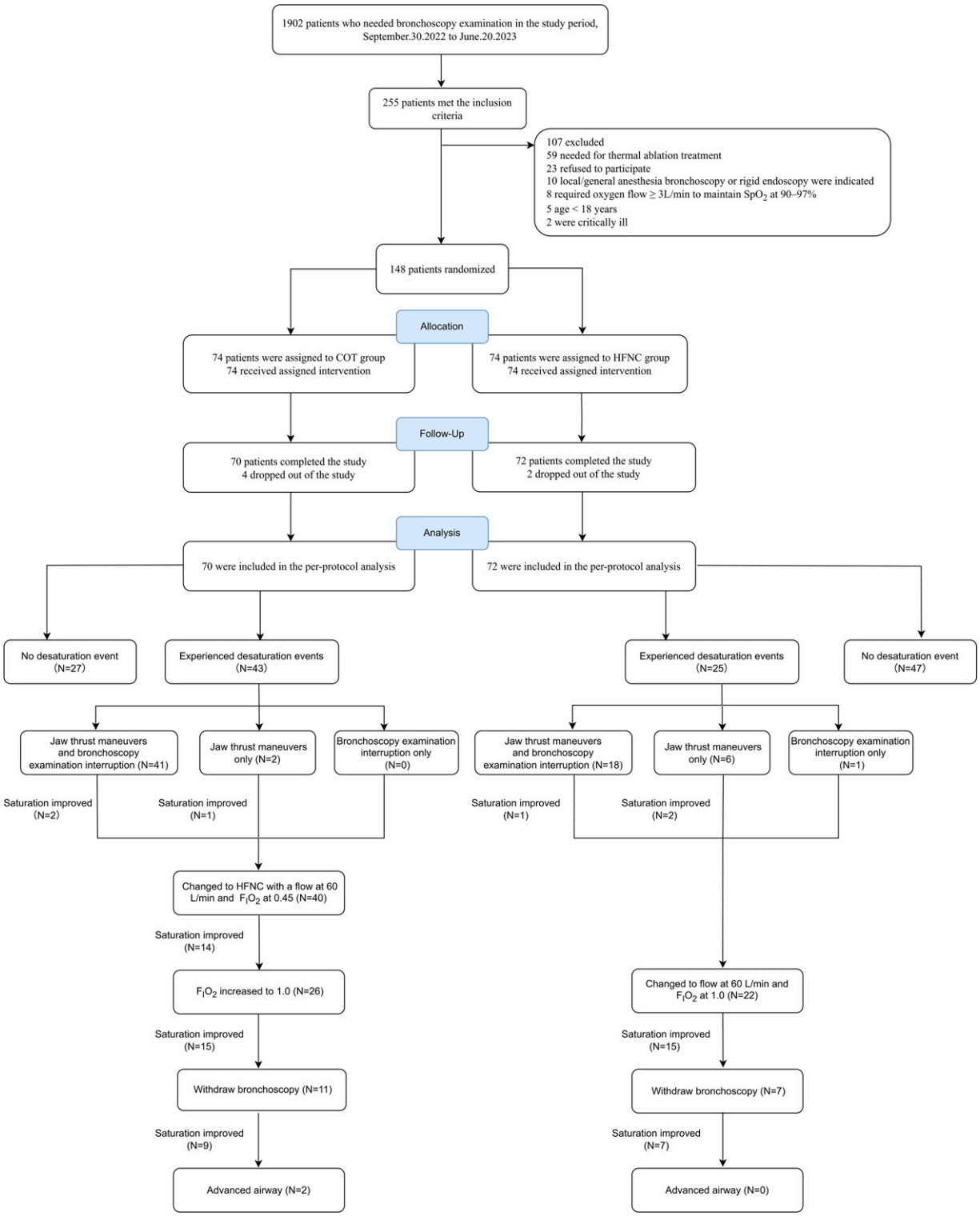

Figure 1. Consolidated Standards of Reporting Trials (CONSORT) flow diagram of the trial. COT = conventional oxygen therapy; FI_{O_2} = fraction of inspiration oxygen; HFNC = high-flow nasal cannula; Sp_{O_2} = pulse oximetry.

Table 1. Characteristics of patients at baseline (per protocol population)

Characteristic	COT ($n = 70$)	HFNC ($n = 72$)
Age, yr	54.5 (36.0–65.3)	57.0 (38.3–69.8)
Male	37 (52.9)	37 (51.4)
BMI,* kg/m^2	22.1 (19.8–24.8)	21.0 (19.3–23.4)
Smoking history	11 (15.7)	20 (27.8)
Pack-years	25.0 (20.0–40.0)	30.0 (16.3–47.5)
Comorbidities		
Tuberculosis	16 (22.9)	19 (26.4)
Lung cancer	8 (11.4)	9 (12.5)
COPD	4 (5.7)	5 (6.9)
Other respiratory diseases	7 (10.0)	3 (4.2)
Other systemic diseases	26 (37.1)	24 (33.3)
CCI score	1 (1, 2)	1 (1, 2)
Diagnosis		
Uncertain lung shadows	9 (12.9)	11 (15.3)
Tracheobronchial stenosis	61 (87.1)	61 (84.7)
Central airway stenosis	48 (68.6)	42 (58.3)
Degree of stenosis, %	30.0 (15.0–41.0)	27.0 (10.0–50.0)
Stenosis site		
Trachea	27 (56.3)	25 (59.5)
Right main bronchus	6 (12.5)	7 (16.7)
Left main bronchus	6 (12.5)	6 (14.3)
Mixed	9 (18.8)	4 (9.5)
Pleural effusion		
Unilateral	13 (18.6)	19 (26.4)
Bilateral	4 (5.7)	5 (6.9)
Reasons for bronchoscopy examination		
Unidentified lesions in the lungs	4 (5.7)	4 (5.6)
Understanding airway status	3 (4.3)	2 (2.8)
Unexplained cough	1 (1.4)	0
Collect lower respiratory tract secretions	8 (11.4)	9 (1.3)
Treatment such as balloon dilation	54 (77.1)	57 (79.2)
Sp_{O_2}, %	98.0 (95.0–99.3)	98.0 (96.0–99.8)
Respiratory rate, bpm	20.0 (16.0–20.0)	20.0 (18.0–21.0)
Requirement of oxygen therapy before study enrollment	8 (11.4)	13 (18.1)
Oxygen flow, L/min	2.0 (2.0–2.8)	2.0 (2.0–3.0)
High risk factors for study inclusion		
Hypoxemia	6 (8.6)	10 (13.9)
Hypercapnia	5 (7.1)	2 (2.8)
Airway stenosis	60 (85.7)	62 (86.1)
Morbidly obese (BMI $\geq$ 30 kg/m^2)	4 (5.7)	0

Definition of abbreviations: BMI = body mass index; CCI = Charlson Comorbidity Index; COPD = chronic obstructive pulmonary disease; COT = conventional oxygen therapy; HFNC = high-flow nasal cannula; Sp_{O_2} = pulse oximetry.
Data are presented as *n*, *n* (%), or median (interquartile range).
*The BMI is the weight in kilograms divided by the square of the height in meters.

Discussion

In this RCT, we found that HFNC significantly reduced the occurrence of hypoxemic events during bronchoscopy examination in patients with high-risk factors, thereby diminishing the subsequent need for desaturation management, including jaw thrust maneuvers, bronchoscopy interruption, and treatment escalation. In addition, HFNC reduced the maximum levels of Ptc_{CO_2} during bronchoscopy examination.

Prior studies have consistently demonstrated HFNC's superiority over COT in reducing hypoxemia occurrence (11–13, 22, 28) and the need for airway intervention and bronchoscopy examination interruptions (28), together with fewer adverse events (12, 13), shorter duration of bronchoscopy examination (12), and greater patient comfort (13). However, the reported occurrence of hypoxemia with HFNC in these RCTs ranged from 5.9% to 13.3% (11–13, 22), contrasting with the 34.7% occurrence in our study. This difference suggests that the indiscriminate use of HFNC might be unnecessary.

To date, only two studies have specifically targeted high-risk patients. Zhang and colleagues (8) reported significant reductions in hypoxemia occurrence and the need for airway interventions with HFNC compared with tight-fitting masks in high-risk patients, identified via a screening tool for obstructive sleep apnea. Both COT and HFNC groups exhibited lower hypoxemia occurrences (29.2% and 4.6%, respectively) compared with our study's occurrence, suggesting potential inaccuracies in using obstructive sleep apnea screening tools to identify high-risk patients. Moreover, such tight-fitting masks are rarely used in clinical oxygen therapy (29), questioning the generalizability of the study findings to common clinical practice. In contrast, our study used more clinically relevant high-risk factors and a more frequently used COT control, lending substantial clinical relevance to our findings. Ben-Menachem and colleagues identified lung transplant recipients as a high-risk population for hypoxemia and compared HFNC and COT during bronchoscopy (28). They found that HFNC significantly reduced the proportion of patients who had the lowest $Sp_{O_2} < 90\%$ (16.2% vs. 69.2%; $P < 0.001$). Notably, when using the same $Sp_{O_2} < 90\%$ criterion to define hypoxemia, the hypoxemia occurrence in their HFNC group was lower than in ours, possibly because of a lower initial $F_{I_{O_2}}$ of 0.45 in our study compared with 1.0 in theirs. Similarly, all RCTs except one used HFNC at $F_{I_{O_2}}$ of 1.0 during endoscopic examinations, complicating the differentiation of the effects of high flows and high $F_{I_{O_2}}$ levels on oxygenation improvement. In contrast, our study marks the first attempt to discern the individual impacts of flows and $F_{I_{O_2}}$ levels in oxygenation improvement. Riccio and colleagues (20) conducted a study comparing HFNC at 60 L/min with COT at comparable $F_{I_{O_2}}$ levels for morbidly obese patients with a BMI close to 50 kg/m^2 undergoing colonoscopy under procedural sedation. They did not observe significant differences in the occurrence of hypoxemia. The variance between our findings and theirs may stem from differences in patient demographics; they specifically enrolled morbidly obese patients whose airways might be prone to collapse during sedation and may not be adequately maintained by HFNC, whereas none of our patients in the HFNC group had a BMI $\geq$ 30 kg/m^2.

Currently, there is no widely accepted protocol for managing hypoxemia during bronchoscopy. The 2003 St. Vincent's

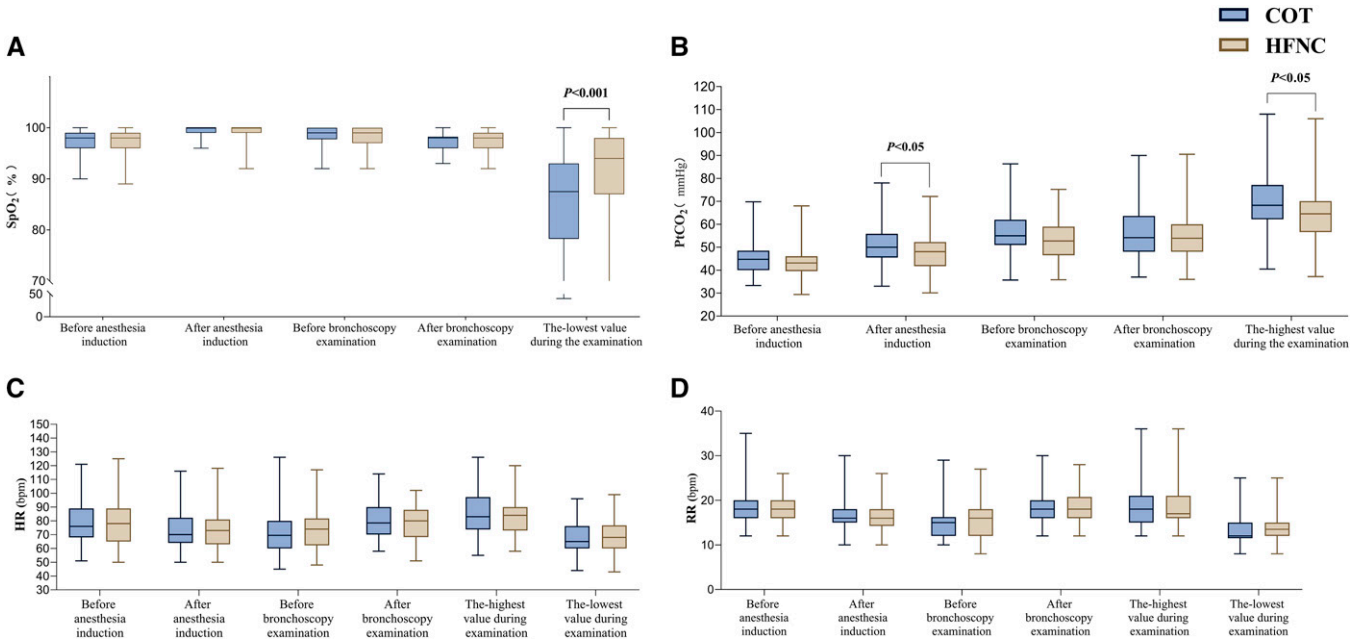

Figure 2. Changes in vital signs during the examination between the two groups. (*A*) Sp_{O_2} (*B*) Ptc_{CO_2} (*C*) HR (*D*) RR. COT = conventional oxygen therapy; HFNC = high-flow nasal cannula; HR = heart rate; Ptc_{CO_2} = transcutaneous carbon dioxide; RR = respiratory rate; Sp_{O_2} = pulse oximetry.

Table 2. Variables during the bronchoscopy examination

	COT	HFNC	*P* Value
No. of patients	70	72	—
Dosage of lidocaine for topical anesthesia, mg	100 (60–100) (*n* = 70)	100 (100–100) (*n* = 72)	0.664
Anesthesia induction			
Dexmedetomidine, ug/kg · h	12.0 (0.9–1.6) (*n* = 70)	1.0 (1.0–1.60) (*n* = 71)	0.883
Remifentanil, TCI, ng/ml	2.5 (2.0–2.5) (*n* = 67)	2.5 (2.0–2.5) (*n* = 65)	0.330
Propofol, mg	30.0 (20.0–40.0) (*n* = 55)	30.0 (20.0–50.0) (*n* = 57)	0.474
Midazolam, mg	2.0 (2.0–2.0) (*n* = 47)	2.0 (2.0–2.0) (*n* = 44)	0.699
Preoxygenation methods			
Nasal cannula	20 (28.6)	14 (19.4)	0.203
Face mask	50 (71.4)	58 (80.6)	—
Oxygen flow, L/min	6.0 (5.0–6.0) (*n* = 70)	6.0 (6.0–6.0) (*n* = 72)	0.013
FI_{O_2}, %	45.0 (41.0–45.0) (*n* = 70)	45.0 (45.0–45.0) (*n* = 72)	0.013
Preoxygenation duration, min	8.0 (5.0–10.0) (*n* = 70)	8.0 (5.0–10.0) (*n* = 72)	0.674
Anesthetic drugs during examination			
Dexmedetomidine, ug/kg · h	0.6 (0.5–0.8) (*n* = 69)	0.6 (0.5–0.8) (*n* = 71)	0.855
Remifentanil, TCI, ng/ml	2.1 (1.9–2.6) (*n* = 66)	2.2 (2.0–2.8) (*n* = 64)	0.675
Propofol, mg	20.0 (15.0–20.0) (*n* = 8)	30.0 (20.0–50.0) (*n* = 11)	0.044
Cough reflex			
0	1 (1.4)	1 (1.4)	0.172
1	42 (60.0)	54 (75.0)	
2	25 (35.7)	17 (23.6)	
3	2 (2.7)	0	
MOAA/S score			
2	53 (75.7)	59 (81.9)	0.363
3	17 (24.3)	13 (18.1)	
Procedural type			
Diagnostic procedure	22 (31.4)	21 (29.2)	0.203
Therapeutic procedure	43 (61.4)	50 (69.4)	
Both	5 (7.1)	1 (1.4)	
Nose bleeding	2 (2.9)	1 (1.4)	0.543

Definition of abbreviations: COT = conventional oxygen therapy; FI_{O_2} = fraction of inspiration oxygen; HFNC = high-flow nasal cannula; MOAA/S = Modified Observer's Assessment of Alertness/Sedation; TCI = target controlled infusion.
Data are presented as *n*, *n* (%), or median (interquartile range).

Table 3. Comparison of outcomes between groups

	COT	HFNC	*P* Value
No. of patients	70	72	—
Primary outcome: desaturation during bronchoscopy examination	43 (61.4)	25 (34.7)	0.016
1 desaturation episode	33 (76.7)	19 (76.0)	—
2 desaturation episodes	9 (20.9)	5 (20.0)	—
3 desaturation episodes	1 (2.3)	1 (4.0)	—
Secondary outcome			
Interval between bronchoscopy insertion to the first desaturation, min	6.0 (3.0–8.0) ($n = 43$)	5.0 (3.0–9.0) ($n = 25$)	0.672
Jaw thrust maneuvers	43 (61.4)	24 (33.3)	0.001
Bronchoscopy examination interruptions	41 (58.6)	19 (26.4)	<0.001
1 interruption	40 (57.1)	17 (23.6)	—
2 interruptions	1 (1.4)	2 (2.8)	—
Oxygen therapy escalation	40 (57.1)	22 (30.6)	0.001
Escalation methods			
Change to HFNC and FI_{O_2} 0.45	14 (20)	NA	—
Increase flow to 60 L/min and FI_{O_2} 1.0	26 (37.1)	22 (30.6)	0.26
Nasopharyngeal/oropharyngeal airway	2 (2.9)	0	—
Intubation	0	0	—
Bronchoscopy withdrawal	11 (15.7)	7 (9.7)	0.283
Duration of desaturation, s	60.0 (30.0–60.0) ($n = 43$)	60.0 (30.0–60.0) ($n = 25$)	0.442
Duration of examination, min	24.0 (13.0–40.0)	21.0 (14.0–34.5)	0.446
Extreme values during the examination			
Lowest Sp_{O_2}, %	87.5 (79.0–93.0)	94.0 (87.0–98.0)	0.001
Highest Ptc_{CO_2}, mm Hg	68.3 (62.3–77.0)	64.6 (56.8–70.1)	0.039
Adverse events			
Hypotension	4 (5.7)	2 (2.8)	0.384
Other	1 (1.4)	0	0.309

Definition of abbreviations: COT = conventional oxygen therapy; FI_{O_2} = fraction of inspiration oxygen; HFNC = high-flow nasal cannula; NA = not applicable; Sp_{O_2} = pulse oximetry; Ptc_{CO_2} = transcutaneous carbon dioxide.
Data are presented as *n*, *n* (%), or median (interquartile range).

stepwise approach suggests escalating oxygen to 6 L/min and using jaw thrust maneuvers (30); if these steps fail to improve oxygenation, a nasopharyngeal airway should be inserted and oxygen delivered via a 7 F catheter near the larynx or trachea. Persistent desaturation calls for bronchoscope withdrawal or sedation reversal (30). However, using a nasopharyngeal airway and a 7 F catheter is rare, and their effectiveness in enhancing oxygenation is debated because of the discomfort and difficulty in placement. In many institutions, if oxygenation does not improve with jaw thrust maneuvers and 6 L/min oxygen, the common response is to withdraw the bronchoscope, reverse sedation, and possibly proceed to intubation. However, repeatedly inserting and withdrawing a bronchoscope in the nasal cavity can lead to laryngeal spasms, nasal bleeding, and discomfort for the patient (29, 31–33). In our study, jaw thrust maneuvers and/or bronchoscopy interruption only marginally improved oxygenation in a few patients (three in each group). Contrastingly, using HFNC at 60 L/min with an FI_{O_2} of 0.45 prevented the need for bronchoscope withdrawal and sedation reversal in 14 out of 40 patients in COT group, with an increase in FI_{O_2} to 1.0 further obviating the need for these interventions in another 15 patients. Altogether, HFNC was effective in maintaining $Sp_{O_2} > 90\%$ for 72.5% (29/40) of patients, for whom COT at 6 L/min and manual interventions were insufficient. In all, the use of HFNC, particularly at the maximum setting, reduces the need for repeated bronchoscope insertions and sedation reversal, thereby decreasing procedure duration and enhancing patient comfort.

In Tao and colleagues' systematic review and meta-analysis assessing the efficacy of HFNC for patients undergoing endoscopic examinations, findings from five studies involving 238 patients indicated no significant differences in end-procedure Pa_{CO_2} or Ptc_{CO_2} levels between the HFNC and COT groups (34). However, in our study, we observed a lower maximum Ptc_{CO_2} level. It is worth noting that our study focused solely on the highest Ptc_{CO_2} level during bronchoscopy examinations rather than at the end of the procedure. During bronchoscopy, factors such as procedural sedation, increased airway resistance, anxiety, irritation, and discomfort can lead to heightened CO_2 production, potentially resulting in the peak level occurring during the examination rather than at the end. Thus, our assessment of the highest Ptc_{CO_2} level may provide a more accurate reflection of the advantages of HFNC over COT in CO_2 clearance.

Strengths and Limitations

Our study presents several notable strengths. First, compared with two prior RCTs investigating HFNC use in high-risk patients, our study stands out for its selection of clinically relevant high-risk factors and control group. Second, we distinguish between the effects of high flows and high FI_{O_2} levels on oxygenation improvement, a novel aspect in our research. Third, we provide a practical treatment algorithm for managing hypoxemia during bronchoscopy examinations, accompanied by detailed results at each step. This elucidates the marginal benefits of interventions such as jaw thrust maneuvers and/or bronchoscopy interruptions, as well as the advantages of HFNC usage.

Our study also has several limitations. First, it enrolled patients with four different risk factors and did not limit the types of bronchoscopy procedures. Thus, our findings might not apply to any specific group, such as morbidly obese patients. In addition, critically ill patients requiring noninvasive ventilation or endotracheal intubation to maintain oxygenation during bronchoscopy examinations were excluded, which means that our study findings cannot be applied to these patients. Furthermore, the primary population included in the study consisted of patients with tracheobronchial stenosis; therefore, further research is needed to explore the application of HFNC in managing other high-risk diseases.

Conclusions

In high-risk patients with predominant airway stenosis undergoing bronchoscopy, HFNC demonstrates advantages over COT by reducing the occurrence of hypoxemia, the need for bronchoscopy interruptions, and treatment escalation, as well as lowering the maximum level of Ptc_{CO_2} during procedures. ■

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