ISSN: 2755-9858

Journal of Otolaryngology Research & Reports

SCIENTIFIC Research and Community

Review Article

Open Access

Safety and Feasibility of Superimposed High-Frequency Jet Ventilation In Rigid Bronchoscopy: A Multi-Centre Prospective Observational Study

Georgia Riepl[1], Gabriela Koller-Halmer[2], Hubert Koller[3], Alexander Aloy[4*], Arschang Valipour[3], Wolfgang Oczenski[1] and Stefan Watzka[5]

[1]Department of Anaesthesia and Intensive Care Medicine, Community Hospital Wien SMZ Baumgartner Höhe-Otto-Wagner Spital, Vienna, Austria

[2]SMZ Süd Kaiser-Franz-Josef-Spital, Vienna, Austria

[3]Department of Pulmonology, SMZ Baumgartner Höhe-Otto-Wagner Hospital, Vienna, Austria

[4]Institute of Fluid Mechanics and Heat Transfer TU Wien, Vienna, Austria

[5]Department of Thoracic Surgery, SMZ Baumgartner Höhe-Otto-Wagner Hospital, Vienna, Austria

ABSTRACT

Background: Rigid bronchoscopy is an established procedure that is increasingly performed under jet ventilation. Superimposed High-Frequency Jet Ventilation (SHFJV) offers potential benefits in airway management. This study aimed to evaluate the safety, feasibility and haemodynamic stability of SHFJV in patients with varying American Society of Anaesthesiologists (ASA) physical status risk levels (ASA I/II versus ASA III/IV).

Methods: A total of 290 patients undergoing rigid bronchoscopy were ventilated using SHFJV via the TwinStream™ ventilator, which delivers two jet streams. The cohort included 100 patients classified as ASA I/II and 190 patients as ASA III/IV. Total intravenous anaesthesia (TIVA) was administered to all patients. Continuous monitoring included arterial oxygen saturation (SaO_2), end-tidal carbon dioxide ($etCO_2$), fraction of inspired oxygen in the airway (FiO_2-aw), driving pressures at high (p-HF) and normal frequency (p-NF), positive end-expiratory pressure (PEEP), peak inspiratory pressure (PIP), blood pressure and heart rate, recorded at 5-min intervals.

Results: No significant differences in SaO_2 were observed between the ASA groups ($p = 0.2112$); however, SaO_2 increased significantly over the duration of ventilation ($p < 0.0001$). CO_2 levels did not differ significantly between the two groups, and hypercapnia was not observed. FiO_2-aw was significantly higher in ASA III/IV patients ($p < 0.0167$).

Conclusion: Rigid bronchoscopy with SHFJV is feasible and haemodynamically stable in patients with elevated ASA III/IV risk, supporting its safe application across a broad spectrum of anaesthetic risk profiles.

***Corresponding author**
Alexander Aloy, Institute of Fluid Mechanics and Heat Transfer TU Wien, Vienna, Austria.

Received: May 27, 2026; **Accepted:** June 01, 2026; **Published:** June 10, 2026

Keywords: Anaesthesia, Bronchoscopy, High-Frequency Jet Ventilation, Oxygenation, Rigid Bronchoscopy, Superimposed High-Frequency Jet Ventilation

Introduction

Rigid Bronchoscopy has firmly established itself as the standard method in interventional pulmonology [1]. Unlike flexible bronchoscopes, rigid bronchoscopes feature a substantially larger working channel, allowing pneumologists to perform complex airway procedures. Traditional assisted or intermittent positive pressure ventilation methods previously used for rigid bronchoscopy have largely been supplanted by jet ventilation, which provides improved surgical conditions, particularly for procedures involving the larynx and trachea [2,3]. Among the available techniques, Superimposed High-Frequency Jet Ventilation (SHFJV) offers distinct advantages. By combining High-Frequency (HF) jets, which maintain oxygenation, with Normal-Frequency (NF) jets, which facilitate carbon dioxide (CO_2) elimination, SHFJV optimises gas exchange during rigid bronchoscopy [4]. The low-frequency jet generated by the respirator creates an upper pressure plateau, while the HF jet produces a lower pressure plateau, resulting in a pulsating Positive

End-Expiratory Pressure (PEEP). Rigid bronchoscopes of various sizes have been specifically developed for superimposed jet ventilation (Figure.1). These instruments feature two adjacent jet nozzles for the low-frequency and HF streams integrated proximally, alongside connections for pressure monitoring, end-tidal CO2 (etCO2) and fraction of inspired oxygen (FiO2) measurement on the opposite side. A proximal window is not required. Effective use of SHFJV necessitates specialised training in both respirator operation and the connection of the jet lines to the rigid bronchoscope.

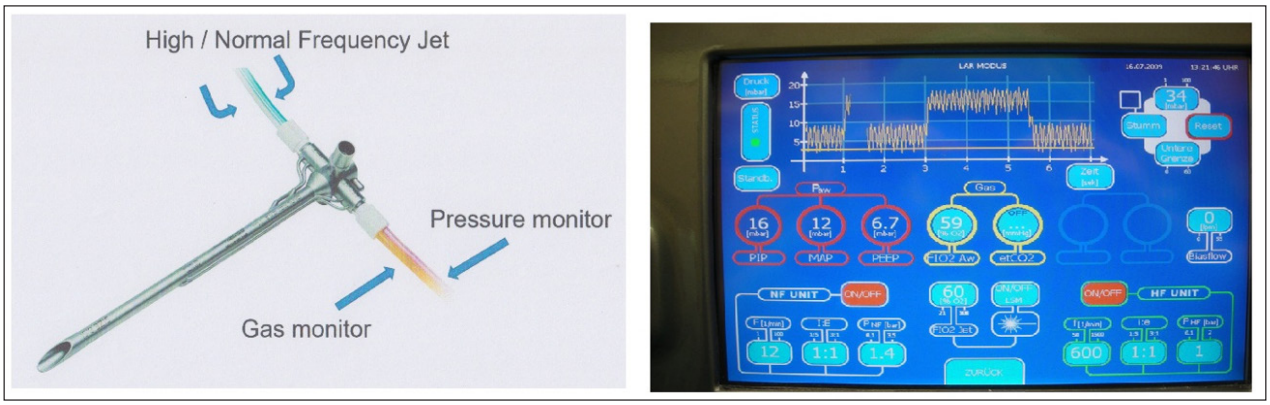

Figure 1: SHFJV Unit, Including Rigide Bronchoscope with Integrated Nozzles for High-Frequency and Low-Frequency Jet Ventilation on One Side and Connections for Pressure Measurement and etCO$_2$ Monitoring on the Other Side

Although SHFJV has demonstrated promise in providing optimal pneumological conditions, evidence regarding its safety and effectiveness across different patient risk profiles and clinical indications remains limited. Further investigation is particularly important for assessing whether it can be used in patients with elevated anaesthetic risk (American Society of Anaesthesiologists [ASA] III/IV), including those for whom conventional ventilation methods may be unsuitable. Therefore, the primary aim of this study was to evaluate oxygenation and CO_2 elimination in patients classified as ASA I/II and ASA III/IV, thereby assessing the safety and feasibility of SHFJV. To this end, we examined the influence of standard ventilation parameters on the behaviour of key clinical variables within these two risk groups. Additionally, the study sought to assess the suitability of SHFJV for a range of endoscopic surgical procedures, with the goal of ensuring optimal procedural conditions.

Methods

Study Design

This was a multi-centre, prospective, observational study conducted across four medical centres with surgical departments. The study protocol was approved by the Vienna Research Ethics Committee (decision of 24 April 2013, EK 12-245-0213), and all participants provided written informed consent prior to inclusion. Patients were stratified into two cohorts according to the ASA physical status classification (I–IV). Cohort 1 comprised patients classified as ASA I/II, while cohort 2 included those classified as ASA III/IV.

Population

Patients were recruited between December 2013 and March 2021 to undergo diagnostic or therapeutic rigid bronchoscopy at a specialised centre for interventional bronchoscopy and thoracic surgery

Patient Cohort

A total of 310 patients were included in the study. Indications for rigid bronchoscopy were as follows: suspected tumour (n = 76), staging before or after chemotherapy (n = 74), unclear chest pathology (n = 60), lung volume reduction with valves (n = 25), repeated bronchoscopy for follow-up care (n = 25), tuberculosis (n = 21), haemoptysis (n = 13), stenting (n = 10), recurrence after lobectomy (n = 5) and foreign body removal (n = 1). ASA classification was available for 290 patients; in 20 patients, the ASA group was unknown. Of the classified patients, 100 were assigned to ASA I/II and 190 to ASA III/IV. The mean age was 57.31 ±12.88 years in the ASA I/II group and 62.74 ± 11.36 years in the ASA III/IV group. Clinical and demographic characteristics are summarised in Table 1. Compared with ASA I/II, the ASA III/IV group included a significantly higher proportion of men (63.1% vs 49%) and were significantly older (62.7 ± 11.4 vs 57.3 ± 12.9 years), with p = 0.0129 and p = 0.0003, respectively.

Table 1: Baseline Characteristics of Patients

Basic characteristics of patients	**Total N=290**		*ASA I/II N=100*		*ASA III/IV N=190*		*Group differences (p-value)*
	N	**mean±SD or %**	**N**	**mean±SD or %**	**N**	**mean±SD or %**	
Sex							
Male	168	57.9%	48	49.0%	120	63.1%	0.0129
Female	122	42.0%	52	52.0%	70	36.8%	
Age (years)	289	60.86±12.17	100	57.31±12.88	189	62.74±11.36	0.0003
BMI (kg/m^2)	278	25.63±5.23	99	25.37±4.56	179	25.77±5.57	ns
BMI categories (WHO)							
Low (< 21)	50	17.9%	15	15.1%	35	19.5%	
Normal (21–24.9)	89	32.0%	34	34.3%	55	30.7%	ns
High (25–29.9)	88	31.6%	39	39.3%	49	27.3%	
Obese (≥ 30)	51	18.3%	11	11.1%	40	22.3%	

Data are presented as frequencies (N) and mean and standard deviation (SD) for continuous data or percentages (%) for categorical data.

- **Inclusion Criteria:** Patients were eligible for inclusion if rigid bronchoscopy was indicated for diagnostic or therapeutic purposes.
- **Exclusion Criteria:** Patients were excluded if they were unable to provide informed consent. Additional exclusion criteria included intolerance to neck hyperextension or rotation due to a stiff or unstable cervical spine and severe cardiovascular or cerebrovascular disease.
- **Informed Consent:** All patients received a detailed information sheet regarding anaesthesia prior to their procedure, provided by the Austrian Society of Anaesthesiology, Resuscitation and Intensive Care Medicine (ÖGARI). This was followed by a consultation with the anaesthetist responsible for the procedure to address any questions and ensure understanding. For elective procedures, the information sheet was provided at least 24 hours before surgery.

Anaesthesia and Ventilation

Upon arrival in the waiting area, an intravenous line was established. In the bronchoscopy suite, patients were continuously monitored using electrocardiography (ECG), non-invasive blood pressure and pulse oximetry (SaO_2). Following pre-oxygenation with a mask, anaesthesia was induced with propofol (1.5–2.5 mg·kg^{-1}) and remifentanil (1 µg·kg^{-1}). Anaesthesia was maintained via continuous intravenous infusion of propofol at 80 µg·kg^{-1}·min^{-1}.Rocuronium (0.6 mg·kg^{-1}) was administered to facilitate orotracheal intubation using the specially designed rigid bronchoscope, which was inserted by the attending pulmonologist. Once anaesthesia was established, the rigid bronchoscope was positioned intra-tracheally, and the TwinStream™ ventilator (Carl Reiner, Austria) was connected. Superimposed HF and NF jet ventilation was then commenced. Initial ventilator settings were as follows: FiO_2 60%, weight-adjusted emission pressures for HF and NF(p-HF, p-NF) jets set at 0.02 bar per kg, NF ventilation at12 min^{-1} with an inspiratory-to-expiratory ratio (I/E) of 1:1 and HF ventilationat600 min^{-1} with I/E = 1:1. Alarm pressure limits were established at 3mbar and 30 mbar for the lower and upper thresholds, respectively. At the conclusion of the procedure, continuous propofol infusion was discontinued, and neuromuscular blockade was reversed with sugammadex (2–4 mg·kg^{-1}). Once spontaneous breathing resumed, jet ventilation was discontinued and the bronchoscope was withdrawn under suction. Patients received supplemental oxygen via face mask until full responsiveness was achieved, after which they were transferred to the recovery room for ongoing monitoring. In urgent cases, bronchoscopy was also performed on high-risk patients to manage life-threatening conditions or to obtain rapid diagnostic information.

Measurements and Data Handling

SaO_2, $etCO_2$, blood pressure and heart rate were recorded at 5-minute intervals for up to 40 min. The number of available recordings decreased over time depending on the duration of the procedure. Ventilation parameters, including p-NF and p-HF jets (expressed in bar), peak inspiratory pressure (PIP, mbar), mean airway pressure (Paw, mbar) and PEEP (mbar), were monitored continuously throughout the procedure. Intra-tracheal FiO_2 was also recorded continuously, whereas et CO_2 was measured intermittently as required.

The Primary Outcome of Interest of this study was intraoperative oxygenation and CO_2 elimination, assessed via SaO_2 and $etCO_2$, respectively. FiO_2 was also recorded in conjunction with SaO_2. Haemodynamic stability, as indicated by blood pressure and heart rate, was considered an additional key measure of patient well-being.

Secondary endpoints included the effects of specific ventilation parameters, such as PEEP, PIP and p-NF (bar), on intraoperative outcomes. Other secondary considerations encompassed the scope of application of rigid bronchoscopy and anaesthesiological aspects related to the procedure.

Statistical Analyses

Continuous variables were visually presented using boxplots, including mean values. Normally distributed variables are summarised as mean ± standard deviation, whereas non-normally distributed variables are reported as median with minimum and maximum values. Categorical variables are presented as frequencies and percentages. Baseline differences between ASA groups were assessed as follows: age and body mass index (BMI) were compared using independent t-tests assuming equal variances; sex was compared using the chi-squared test; and BMI categories, as ordinal variables, were analysed using the chi-squared test for trend.

Linear mixed-effects models with random intercepts and random slopes were fitted to assess whether continuous variables measured over time depended on elapsed time (min), ASA group and their interaction. To evaluate the impact of changes in a continuous variable over time on the outcome, the variable was also included in the model as a covariate. For variables with non-normally distributed residuals, ArcSin transformation was applied to SaO_2 and PEEP ("*ArcSin*" √("*x*/100")), and a base-10 logarithmic transformation was applied to p-NF. Least-square means were subsequently back-transformed for interpretation. A p-value ≤0.05 was considered statistically significant.

Results

Oxygenation and Carbon Dioxide Elimination

SaoO2: SaO_2 did not differ significantly between ASA groups, with back-transformed least-square means of 97.2% for ASA I/II and 96.9% for ASA III/IV, p = 0.2112 (Figure.2). However, SaO_2 increases significantly over time, from a least-square mean of 96.2% at baseline to 98.7% after 20 min (p < 0.0001). No statistically significant differences were observed in the etCO2 values between the two ASA groups. It should be noted that, at baseline for both ASA groups and at 20 min for ASA I/II, only five or fewer observations were available (Figure.3). This limited number of measurements likely explains the observed decrease in $etCO_2$ within the ASA I/II group.

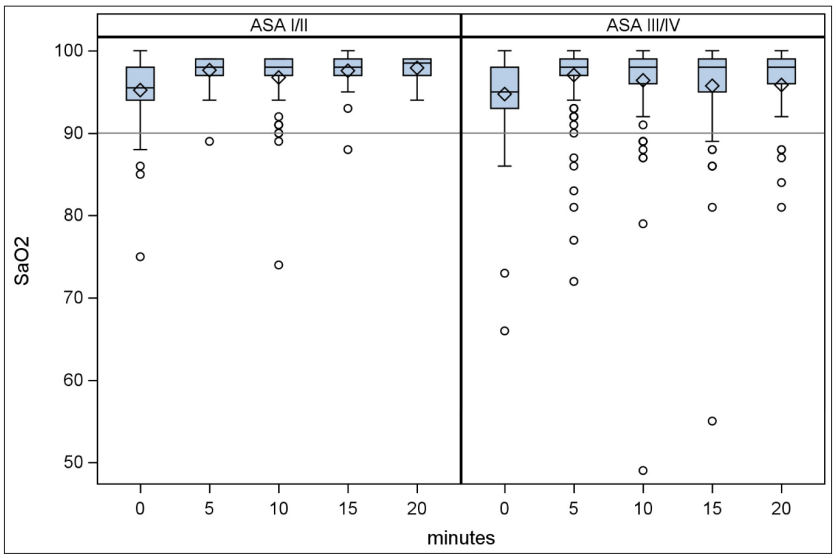

Figure 2: Boxplots of SaO_2 (incl. mean as diamond) in ASA Group I/II and ASA Group III/IV over 20 Minutes. A Reference Line is Drawn at 90% SaO_2. SaO_2 Increases Significantly Over Time (p<0.0001) but no differences between ASA Groups Can be Seen (p=0.2123)

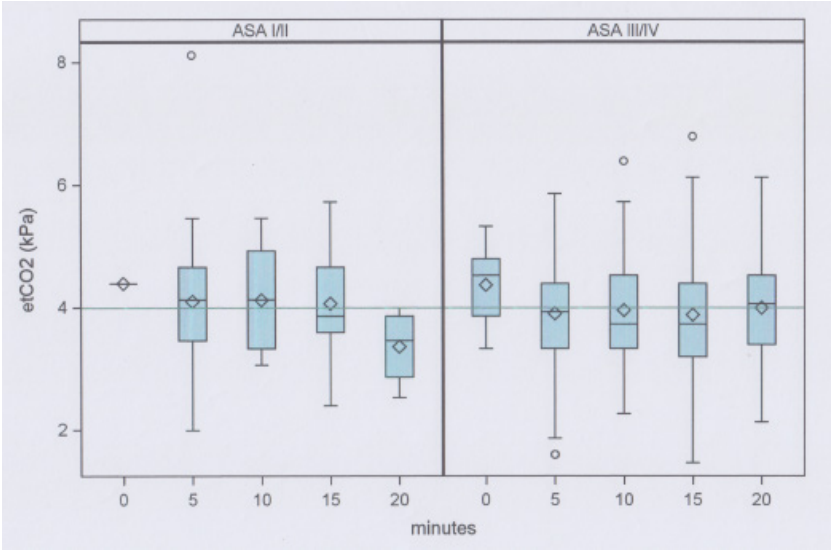

Figure 3: Boxplots of $etCO_2$ (incl. mean as diamond) in ASA group I/II and ASA Group III/IV over 20 Minutes. A Reference Line is Drawn at 4 $etCO_2$

FIO2: FiO_2 was significantly higher in ASA III/IV patients, with a back-transformed least-square mean of 53.8%, compared with 50.1% in ASA I/II patients (p = 0.0167), corresponding to a mean difference of 3.70% (Figure.4). This difference primarily reflects a greater increase in average FiO_2 over time in the ASA III/IV group compared with ASA I/II (p = 0.0391 for the interaction). Specifically, FiO_2 in ASA I/II patients rose from 49.2% at baseline to 52.3% at 20 min, whereas ASA III/IV patients exhibited an increase from 50.4% to 62.0% over the same period.

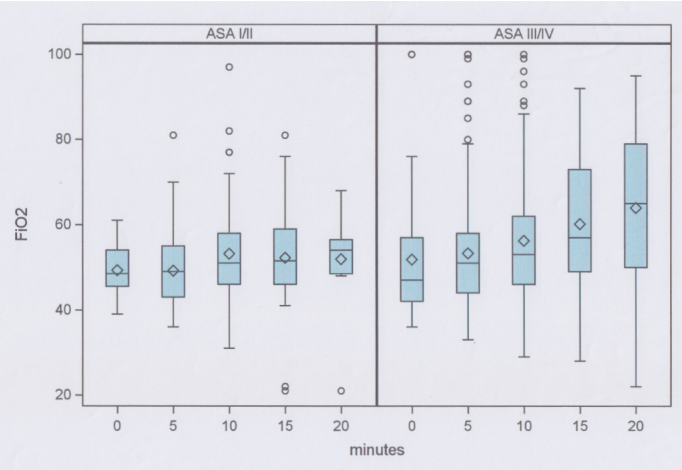

Figure 4: Boxplots of FIO_2 (incl. mean as diamond) in ASA group I/II and in Group III/IV over 20 Minutes

Haemodynamic Parameters: Blood Pressure and Heart Rate
No statistically significant differences were observed between ASA groups for systolic blood pressure, with back-transformed least-square means of 135.1 mmHg for ASA I/II and 134.20 mmHg for ASA III/IV (p = 0.7737). Systolic pressure did not change significantly over time (p = 0.2003).

Diastolic blood pleasure was also comparable between groups, with least-square means of 86.0 mmHg for ASA I/II and 84.8 mmHg for ASA III/IV (p = 05148). However, diastolic blood pressure increased significantly over time, at an average rate of 0.22 mmHg per min (p = 0.0265).

Heart rate was similar between ASA groups (least-square mean 88.7 bpm for both; p = 0.9904) but increased significantly over time, with an average rise of 0.33 bpm (p < 0.0001).

Secondary Outcomes
PEEP: PEEP increased significantly over time (p < 0.0001). Although ASA I/II patients exhibited slightly lower PEEP values (back-transformed least-square mean 1.70 mbar) compared with ASA III/IV patients (2.19 mbar), this difference was not statistically significant (p = 0.9274). No significant ASA group effect was observed for SaO_2 after adjusting for PEEP.

However, the association between PEEP and SaO_2 was time-dependent (p = 0.0240). At baseline, higher PEEP was associated with slightly lower SaO2 (back-transformed least-square means: 96.4% for PEEP = 3,1 mbar and 95.1% for PEEP = 4,9 mbar). In contrast, after 20 min, higher PEEP corresponded to higher SaO2 (98.0% for PEEP = 3,1 mbar and 99.0% for PEEP = 4,9 mbar).

PIP: PIP increased significantly over time (p < 0.0001). The back-transformed least-square mean PIP was 11.7 mbar in the ASA I/II group and 11.4 mbar in the ASA III/IV group, with no statistically significant difference between groups (p = 0.5797).

p-NF: p-NF values did not differ significantly between ASA groups (least-square means: 0.86 for ASA I/II and 0.87 for ASA III/IV; p = 0.7159). However, the temporal change in p-NF differed between groups (p = 0.0237). In the ASA I/II group, p-NF increased slightly from 0.85 at baseline to 0.86 at 20 min, whereas in the ASA III/IV group, the increase was more pronounced, rising from 0.85 to 0.92 over the same period. A positive correlation was observed between p-NF and PIP, with PIP increasing as p-NF increased (p < 0.0001). Furthermore, p-NF significantly influenced SaO_2 (p = 0.0015), with decreasing p-NF values associated with higher SaO_2.

Discussion

Primary Endpoint

The primary endpoints of this study were SaO_2 and CO_2 elimination as measures of intraoperative of oxygenation and ventilation. Our results demonstrate that SaO_2 values in ASA III/IV patients did not differ significantly from those in ASA I/II patients, despite the generally higher anaesthetic risk in the former group. This finding suggests that rigid bronchoscopy with jet ventilation does not increase the risk of inadequate oxygenation, supporting its safety even in emergency settings. A key advantage of jet ventilation for the surgeon is the absence of a ventilation catheter within the bronchoscope, which increases working space and facilitates instrument handling during complex procedures.

As reported in the Results, FiO_2 increased over time in ASA III/IV patients, with back-transformed least-square means of 53.8% compared with 50.1% in ASA I/II patients. These values are clinically acceptable, particularly as the ASA III/IV group included emergency bronchoscopies, where higher FiO_2 levels are generally required.

Regarding $etCO_2$, no statistically significant differences were observed between ASA groups, indicating that etCO2 elimination was effectively maintained across both patient risk profiles. $etCO_2$ values remained within normal ranges even in ASA III/IV patients. A notable decrease in $etCO_2$ was observed at the final measurement in the ASA I/II group, which can be attributed to the removal of surgical instruments that had previously partially obstructed the airway. With these instruments removed, a larger tidal volume became available at the same ventilator settings, explaining the observed drop in $etCO_2$.

Haemodynamic parameters did not differ significantly between ASA groups. Despite the higher baseline risk in ASA III/IV patients, stable circulatory conditions were maintained throughout the procedure. Heart rate was comparable between groups, with both demonstrating a slight but statistically significant increase over time; however, this change was not considered clinically relevant.

Secondary Endpoints

Analysis of secondary endpoints demonstrated a time-dependent relationship between PEEP and SaO_2. Although no effect was observed at baseline, after 20 min higher PEEP was associated with increased SaO2. PEEP was primarily generated by increasing the p-HF and the HF component of ventilation. A similar time-dependent relationship was observed between PIP and SaO_2. While no significant association was evident initially, after 20 min higher PIP correlated with higher SaO2 values, indicating that changes in ventilation pressures over time contributed to improved oxygenation.

Analysis of p-NF revealed that ASA III/IV patients exhibited a greater increase in p-NF over time compared with ASA I/II patients. However, excessive increases in p-NF were associated with a decrease in SaO2, indicating that overly high p-NF should be avoided to maintain optimal oxygenation. CO_2 elimination is influenced by the upper pressure level, which is regulated by p-NF. Increases in p-NF lead to higher PIP and gas volume, thereby reducing $etCO_2$, whereas reductions in p-NF have the opposite effect, increasing $etCO_2$. Contrary to concerns that CO_2 elimination is a limitation of jet ventilation, our results demonstrate that modern monitoring technology allows effective control of

ventilation, and hypercapnia did not occur at any time during the procedures [5]. The observed drop in $etCO_2$ in the ASA I/II group, from 3.9 to 3.3 kPa, can be explained by the removal of surgical instruments from the rigid bronchoscope, which suddenly increased the available gas volume and reduced $etCO_2$. Measured $etCO_2$ correlated well with arterial pCO_2, confirming its reliability for monitoring CO_2 elimination during rigid bronchoscopy [6,7]. Impaired CO_2 elimination was only noted in patients with pre-existing restricted lung function [8]. These findings are consistent with previous reports. Sütterlin and colleagues, in a porcine model, demonstrated that SHFJV achieves higher end-expiratory volumes and more effective gas exchange, including CO_2 removal, compared with HF jet ventilation alone, which was associated with higher rates of hypoxia and hypercapnia [9].

Scope of Application of Rigid Bronchoscopy

The expanding applications of rigid bronchoscopy reflect the evolving and increasingly complex demands of interventional pulmonologists. Jet ventilation minimises movement of structures within the bronchoscopist's field of view. At high ventilation frequencies, lung motion is substantially reduced, rendering the surgical field virtually immobile. This characteristic makes SHFJV particularly suitable for procedures that require minimal lung movement, such as endobronchial ultrasound (EBUS) combined with transbronchial needle aspiration [10]. Importantly, SHFJV imposes no time constraints on the surgeon, allowing cytological and histological samples to be obtained without the pressure associated with limited ventilation time.

Endoluminal Stenting: Early experiences with endoluminal stenting using SHFJV have demonstrated advantages for both surgeons and anaesthetists [11,12]. All commercially available stents can be deployed through the jet laryngoscope, whereas stent placement is not feasible using a catheter. In a recent multi-centre, prospective, randomised controlled trial comparing SHFJV with conventional HF jet ventilation via catheters during interventional bronchoscopy, SHFJV was shown to be both effective and safe [13]. Additional benefits include the absence of any constriction within the operative field, facilitating precise instrument handling.

Laser Application: Procedures such as CO_2 laser ablation and argon plasma coagulation require careful management of oxygen concentration ($FiO_2 \leq 0.4$) and ventilation with an oxygen–air mixture, while avoiding nitrous oxide and inhalational anaesthetics due to the risk of toxic decomposition products. In the context of rigid bronchoscopy, plastic ventilation catheters are contraindicated, making total intravenous anaesthesia (TIVA) the preferred method for safe operation.

Bleeding Management: Bleeding during bronchoscopy can arise from cavernous haemorrhage or tumour-related sources [14,15]. Such bleeding is often managed by tamponade, with the patient's head lowered to facilitate drainage. Contrary to common misconceptions, the jet stream does not atomise blood; the bidirectional gas flow directs blood outward along the bronchoscope edges [16].

Barotrauma: Jet ventilation has historically been associated with complications such as barotrauma. These risks are primarily linked to catheter- or needle-based techniques without adjustable pressure limits, as well as to manual jet ventilation. Consequently, these methods are no longer routinely employed. The reported incidence of barotrauma during rigid bronchoscopy is very low (<0.5%), and no such complications have been observed with SHFJV [17,18]. Although rigid bronchoscopy can occasionally result in iatrogenic pneumothorax, there are no specific data on its incidence under SHFJV. In such cases, jet ventilation should be discontinued and conventional mechanical ventilation initiated. In our study, neither bronchospasm nor laryngospasm complications sometimes observed with assisted spontaneous ventilation were encountered. Wang and colleagues compared SHFJV with conventional HF jet ventilation and confirmed that SHFJV is a safe and effective technique for interventional bronchoscopy, particularly for longer procedures [19]. Analysis of procedural feasibility in high-risk patients with pre-existing bleeding, impending hypoxaemia or impaired CO_2 elimination indicates that, when such interventions are necessary, they can only be safely performed using rigid bronchoscopy under jet ventilation.

Anaesthesia Considerations

Beyond safety, the feasibility of SHFJV under general anaesthesia was a key focus of this study. Evidence indicates that general anaesthesia is safer than moderate sedation, being associated with fewer complications and lower mortality. Moderate sedation has been shown to require more interventions and is linked to a higher incidence of severe bleeding complications. Rigid bronchoscopy performed with muscle relaxation also demonstrates fewer desaturation events and reduced hypercapnia compared with procedures without muscle relaxants. For patients with symptomatic airway obstruction requiring rigid therapeutic bronchoscopy, jet ventilation is recommended, with controlled ventilation reserved for selected circumstances.

In conclusion, SHFJV can be safely applied during rigid bronchoscopy in patients across a spectrum of anaesthetic risk (ASA I/II and ASA III/IV). Rigid bronchoscopy under SHFJV is suitable for all complex surgical techniques, and the ventilation parameters analysed in this study reflect their influence on oxygenation and $etCO_2$ elimination.

References

1. Athanassiadi K, Joong Na K, Zanowska K, Rita Costa, Marcello Migliore, et al. (2025) The utility of a rigid bronchoscope. Breathe 21: 240352.
2. Donner A, Lanzenberger-Schragl E, Kashanipour A, Zimpfer M, Aloy A (1996) Application of SHFJV for surgical procedures. Acta Anaesthesiol Scand Suppl 109: 153-157.
3. Laurie Putz, Alain Mayné, Anne-Sophie Dincq (2016) Jet Ventilation during Rigid Bronchoscopy in Adults: A Focused Review. Biomed Res Int 2016: 4234861.
4. Alexander A (2024) Application of Various High-Frequency Ventilation Techniques during Surgical Procedures on the Larynx and Trachea. Journal of Otolaryngology Research & Reports 3: 1-6.
5. Okamoto S, Somiya N, Saito AM, Akiko Kada, Masahide Oki, et al. (2020) A prospective, randomized trial comparing respiratory status during anesthesia for airwaystenting: spontaneous respiration versus controlled ventilation with muscle relaxants. Anesth 131: 893-900.
6. Koller-Halmer G, Schindler I, Koller H. SHFJV (2011) (super imposed high frequency jet ventilation), EtCO2 correlation to PaCO2 in diagnostic and therapeutic rigid bronchosscopy. European Respiratory Journal 123: A21-A22.
7. Simon M, Gottschall R, Gugel M, Fritz H, Mohr S, et al. (2003) Comparison of transcutaneous and endtidal CO2-monitoring for rigid bronchoscopy during high- frequency jet ventilation. Acta Anaesthesiol Scand 47: 861-867.
8. Biro P, M Layer M, K Wiedemann K, Seifert B, Spahn DR

(2000) Carbon dioxide elimination during high-frequency jet ventilation for rigid bronchoscopy. Br J Anaesth 84: 635-637.
9. Sütterlin R, Priori R, Larsson A, P Frykholm, A Aliverti, et al. (2014) Frequency dependence of lung volume changes during superimposed high-frequency jet ventilation and high-frequency jet ventilation. British Journal of Anaesthesia 112: 141-149.
10. Czarnecka K, Yasufuku K (2015) Endobronchial Ultrasound-guided Transbronchial Needle Aspiration for Staging Patients with Lung Cancer with Clinical N0 Disease. Annals of the American Thoracic Society 12: 297-299.
11. Aloy A, Donner A, Strasser K, Klepetko W, Schragl E, et al. (1991) Jet ventilation superimposed on a special jet laryngoscope for endoluminal stent insertion in the tracheobronchial system (Article in German). Der Anästhesist 43: 262-269.
12. Klepetko W, Müller MR, Grimm M, Aloy A, Kashanipour A, et al. (1991) Endoluminal Stenting of tracheobronchial system. Acta Chirurgica Austriaca 23: 124-128.
13. Yang M, Deng Zh, He X, Jing Guo J, Yang Sh, et al. (2025) Jet ventilation dynamics in rigid bronchoscope: insights from a simulated experimental model. BMC Anaesthesiology 25: 332.
14. Alfaiate A, VerClérigo V, Noivo D, Fernandes LL, Duarte P, et al. (2023) Pharmacological approach to iatrogenic bleeding during bronchoscopy: what do we know so far and where do we go from here?. J Bras Pneumol 49: e20220195.
15. Sakr L, Dutau H (2010) Massive hemoptysis: an update on the role of bronchoscopy in diagnosis and management. Respiration 80: 38-58.
16. Nowak A, Usichenko T, Wendt M, Eckart Klemm E (2013) Methods of administering superimposed high-frequency jet ventilation and the associated risk for aspiration in a model of tracheal bleeding. Respiration 85: 59-63.
17. Udit Chaddha, Septimiu Murgu (2020) Complications of rigid bronchoscopy. Respirology 26: 14-18.
18. Putz L, Mayne A, Dincq AS (2016) Jet Ventilation during Rigid Bronchoscopy in Adults: A Focused Review. BioMed Research International 2016: 4234861.
19. Wang Ting, Yinghua Pei, Xiaojian Qiu, Juan Wang, Yuling Wang, et al. (2025) A multi-centre prospective random control study of superimposed high-frequency jet ventilation and conventional jet ventilation for interventional bronchoscopy. Ear, Nose & Throat Journal 104: 47-53.